

(12) **United States Patent**
West

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(54) **APPARATUS FOR FORMING AND MOUNTING A PHOTOVOLTAIC ARRAY**

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(73) Assignee: **SolarCity Corporation**, San Mateo, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

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(22) Filed: **Feb. 24, 2012**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. 13/351,397, filed on Jan. 17, 2012, now abandoned, which is a continuation of application No. 12/594,935, filed on Oct. 6, 2009, now Pat. No. 8,109,048.

(51) **Int. Cl.**
E04D 13/18 (2014.01)
F16B 5/10 (2006.01)

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(52) **U.S. Cl.**
CPC **F16B 5/10** (2013.01); **F24J 2/523** (2013.01); **F24J 2/526** (2013.01); **F24J 2/5211** (2013.01);

(Continued)

(58) **Field of Classification Search**

CPC F24J 2/5245; F24J 2/5262; F24J 2/5264; F24J 2/511; F24J 2/5243; F24J 2/5252; F24J 2/5254; H01L 31/0424; H01L 31/0482; Y02B 10/12; Y02E 10/47; F16M 13/022
USPC 52/173.3, 582.2, 584.1, 586.1, 586.2, 52/698, 710; 136/244, 251, 252; 126/621, 126/622, 623; 248/220.21, 220.22, 221.11, 248/222.14, 222.13, 237

See application file for complete search history.

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Primary Examiner — Adriana Figueroa

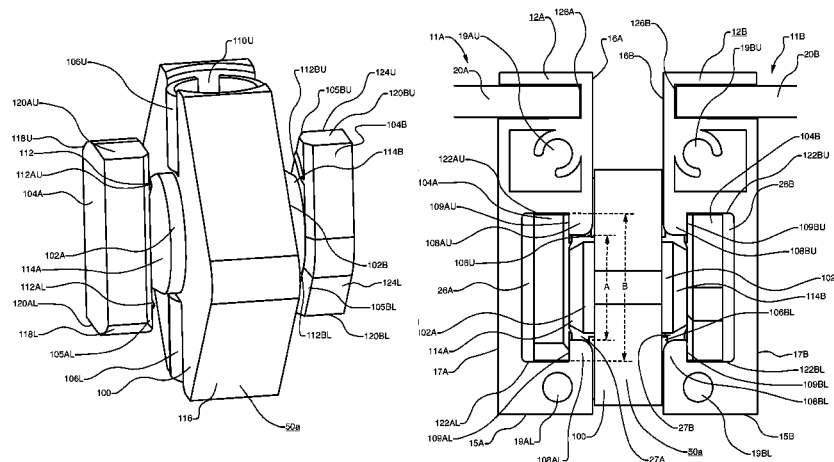
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(57) **ABSTRACT**

A photovoltaic (PV) module framing and coupling system enables the attachment of PV modules to a roof or other mounting surface without requiring the use of separate structural support members which attach directly to and span between multiple PV modules in a formed PV array. The apparatus provides a parallel coupling for securely interlocking the outside surfaces of parallel frame members together in a side to side arrangement to form an array with improved structural load distribution. The coupling may attach to a slot in the frame at substantially any position along the length of the frame thereby enabling the interconnection of adjacent PV modules along both an x and y axis. The apparatus may further provide a rotating portion and locking portion, mounting brackets for direct connection to a mounting surface, grounding teeth, and a twist-lock engagement means for interlocking and aligning PV modules in the array.

9 Claims, 30 Drawing Sheets



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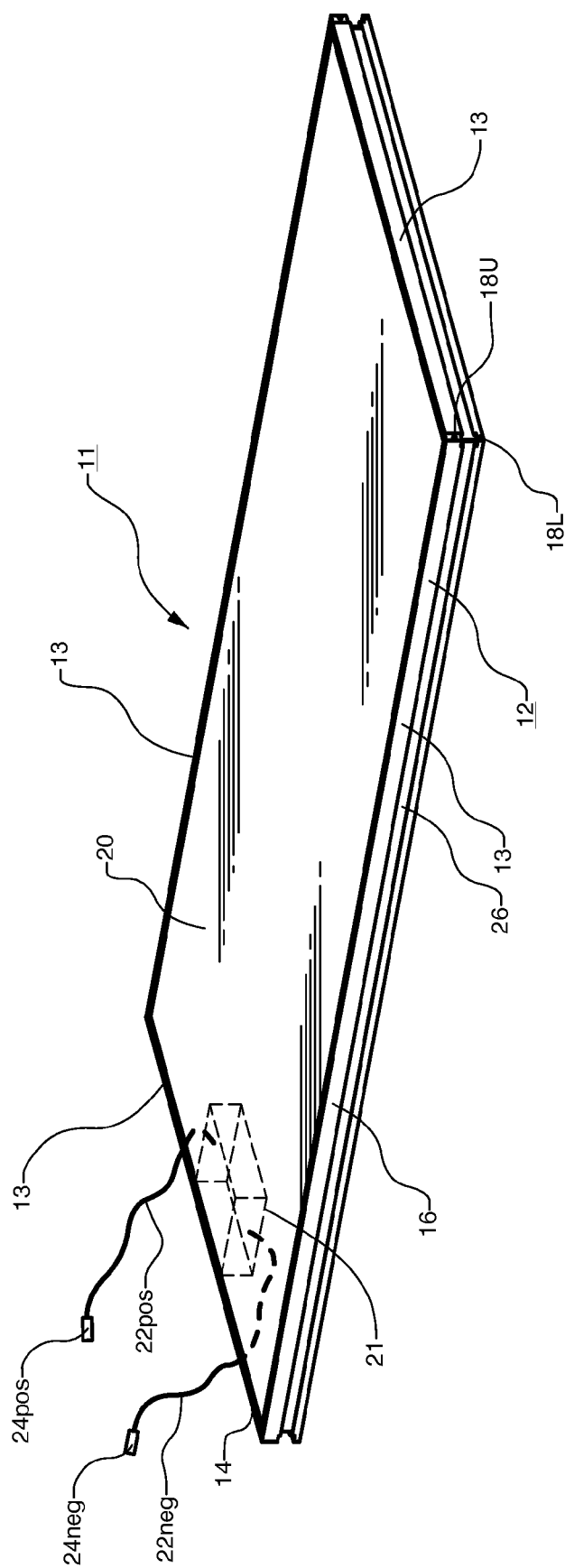


FIG. 1

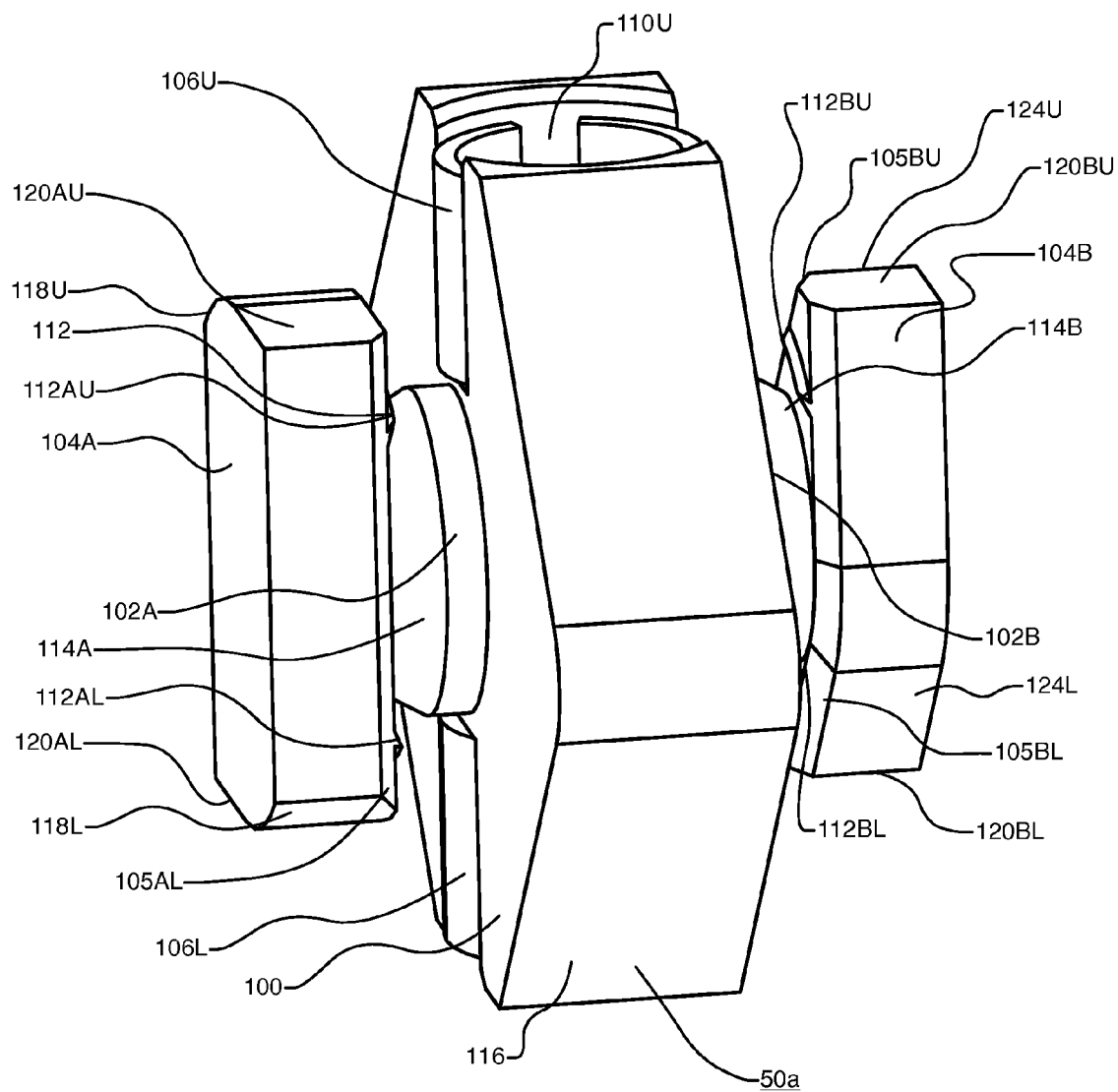


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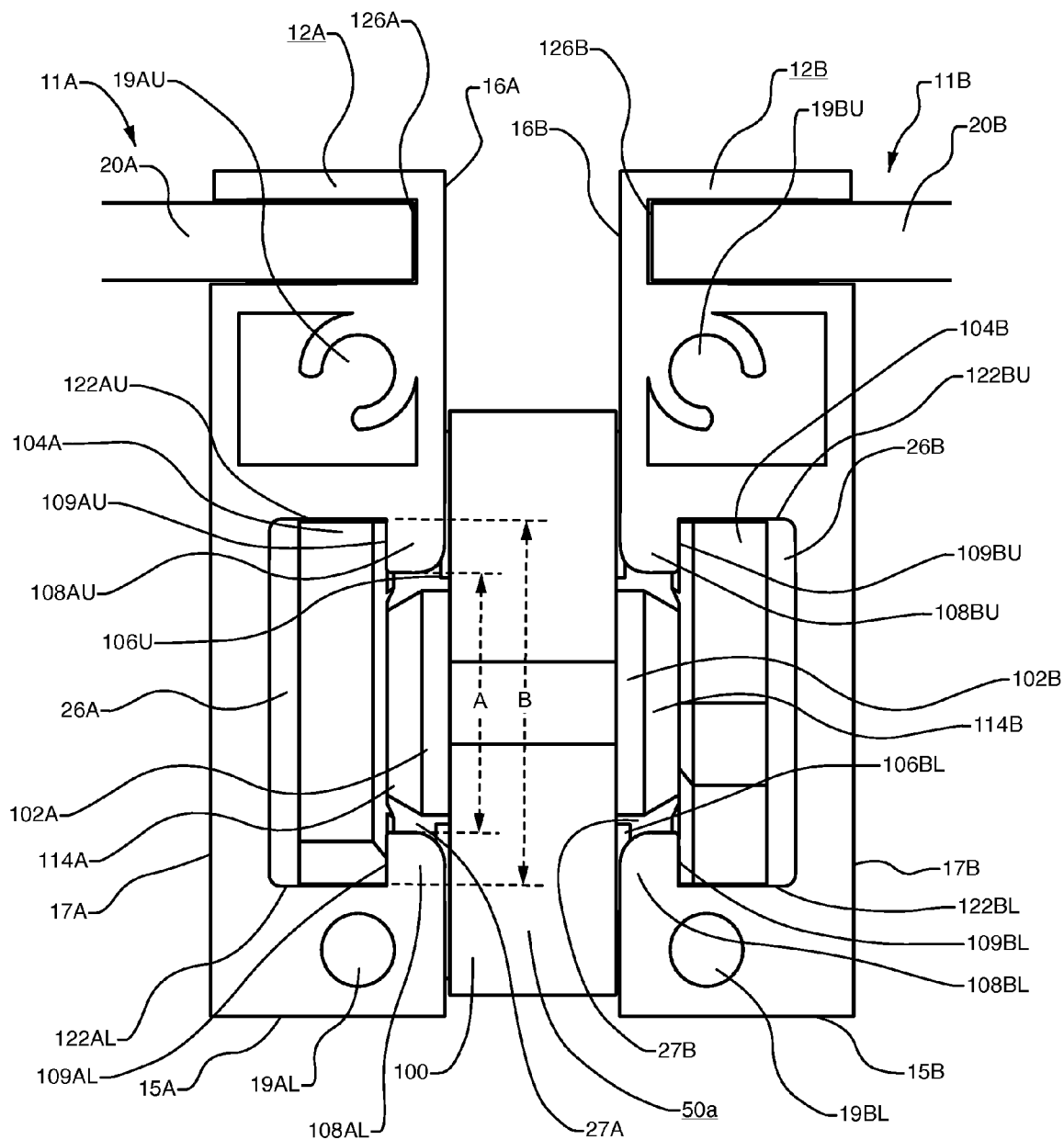


FIG. 3

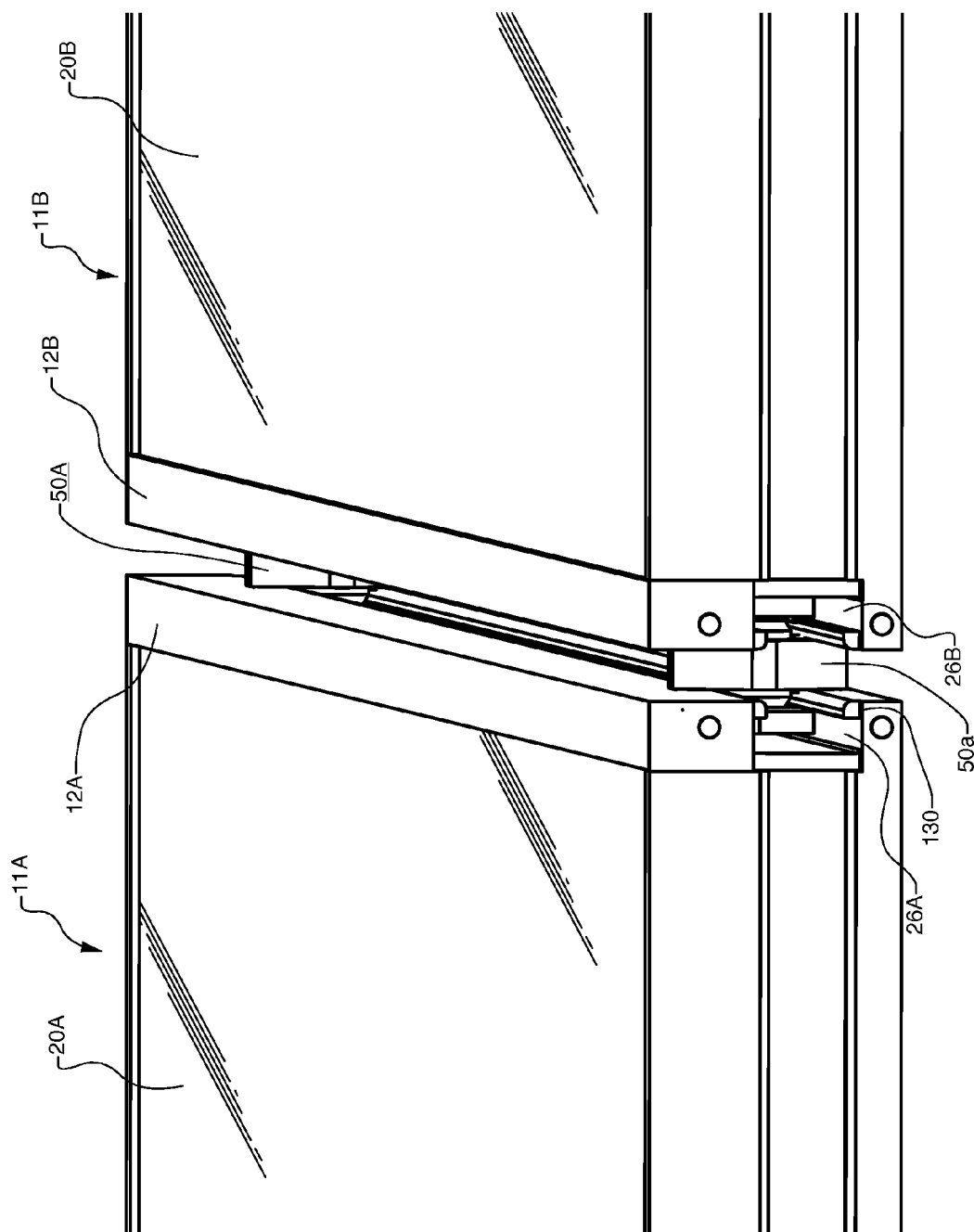


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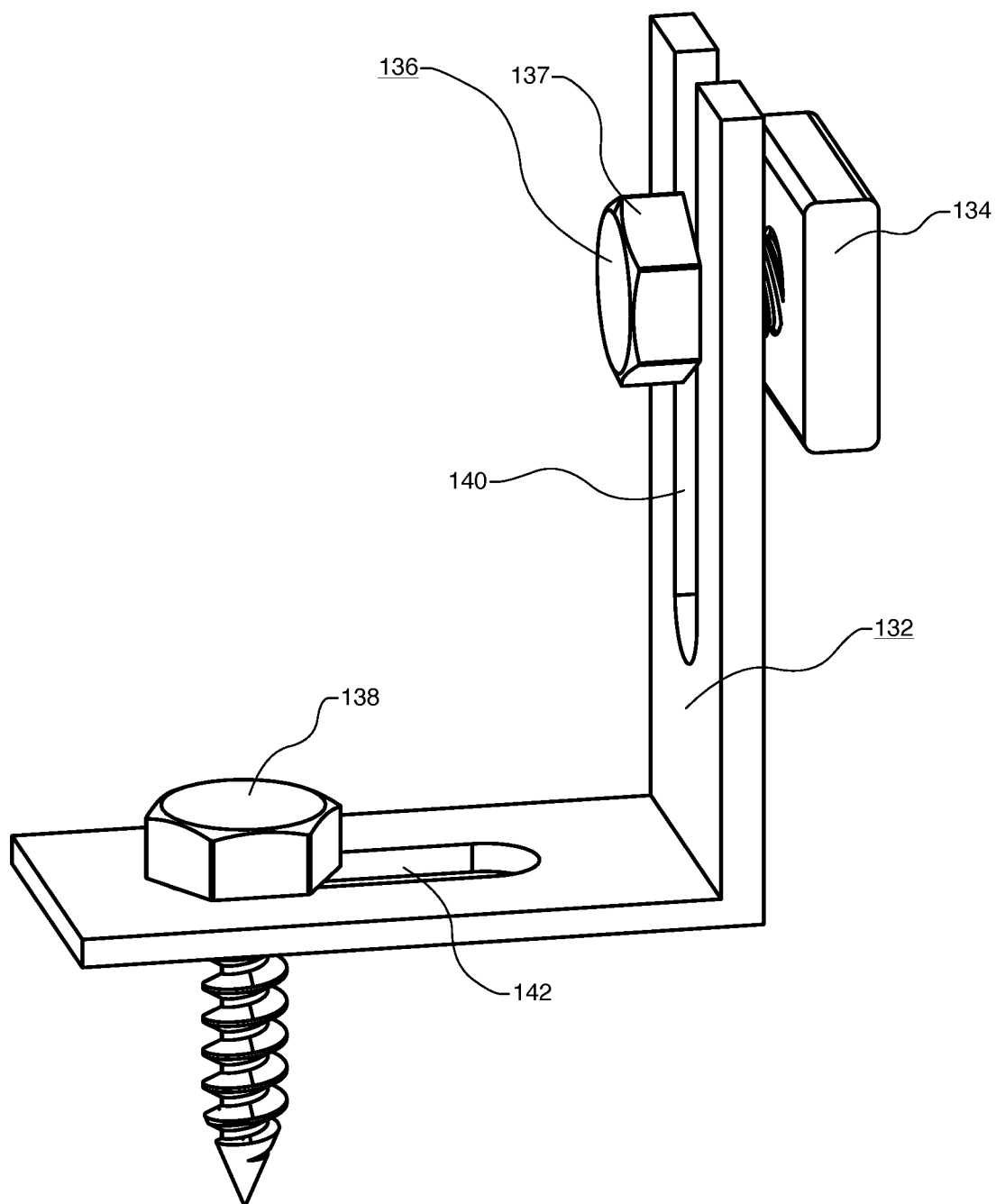


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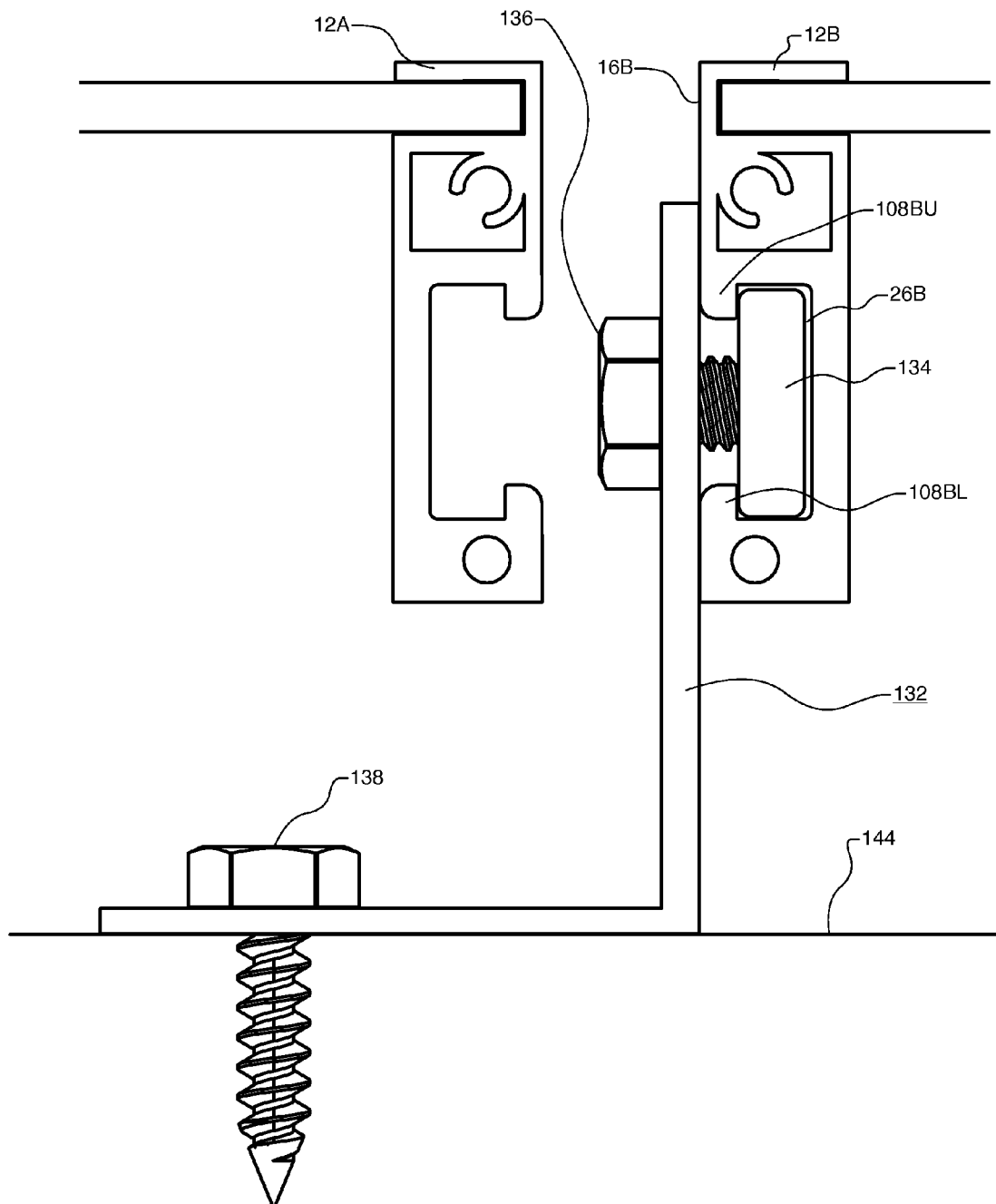


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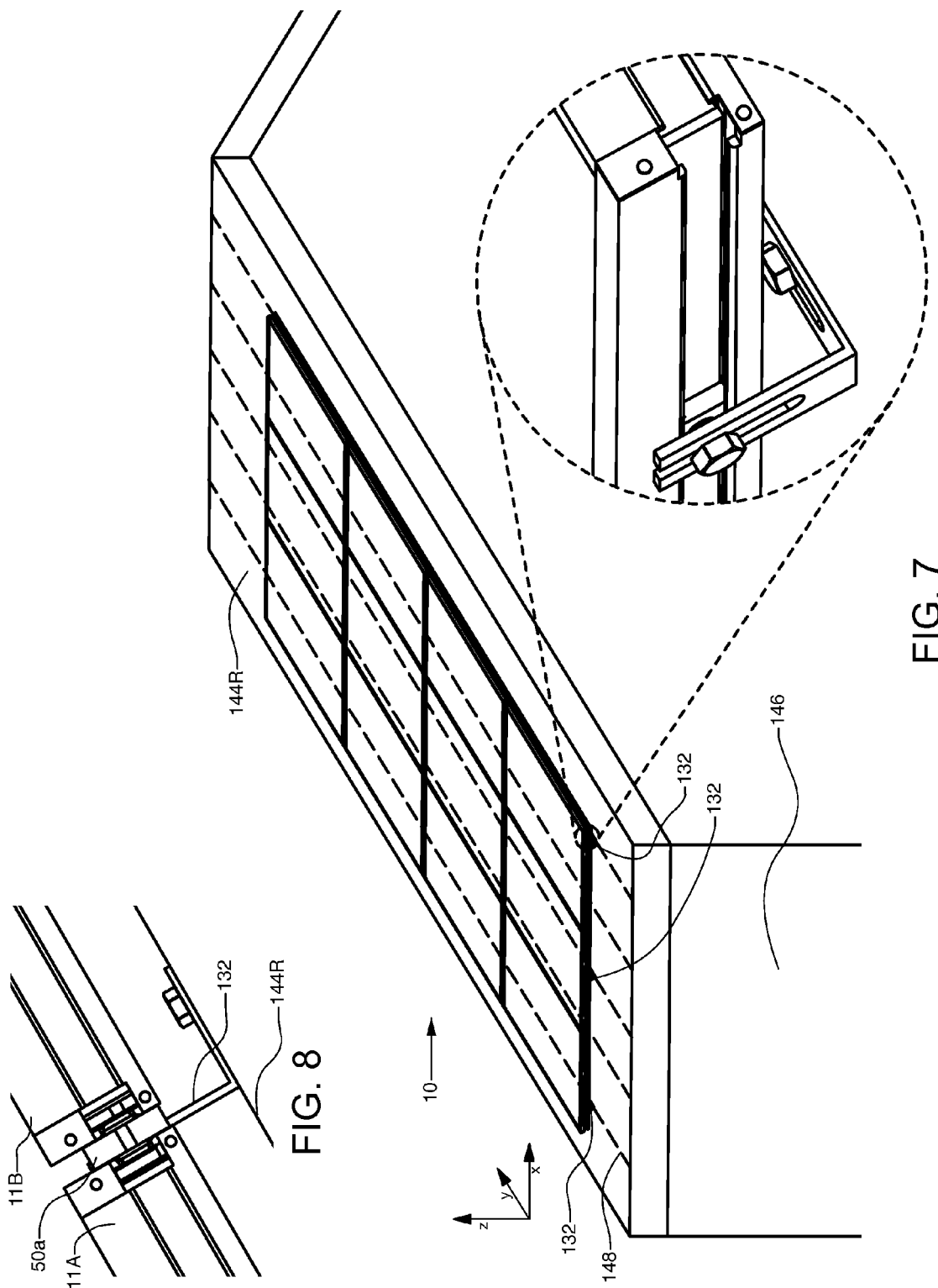


FIG. 7

FIG. 8

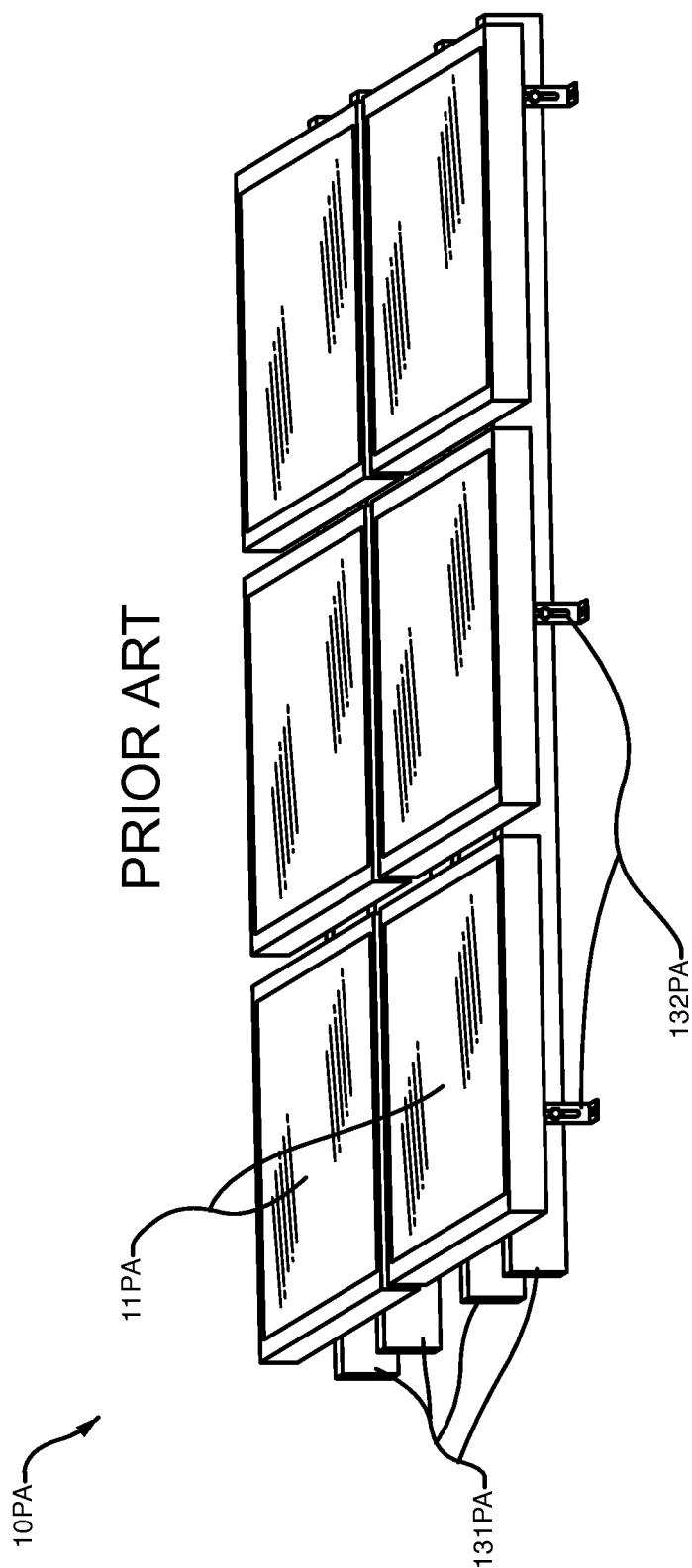


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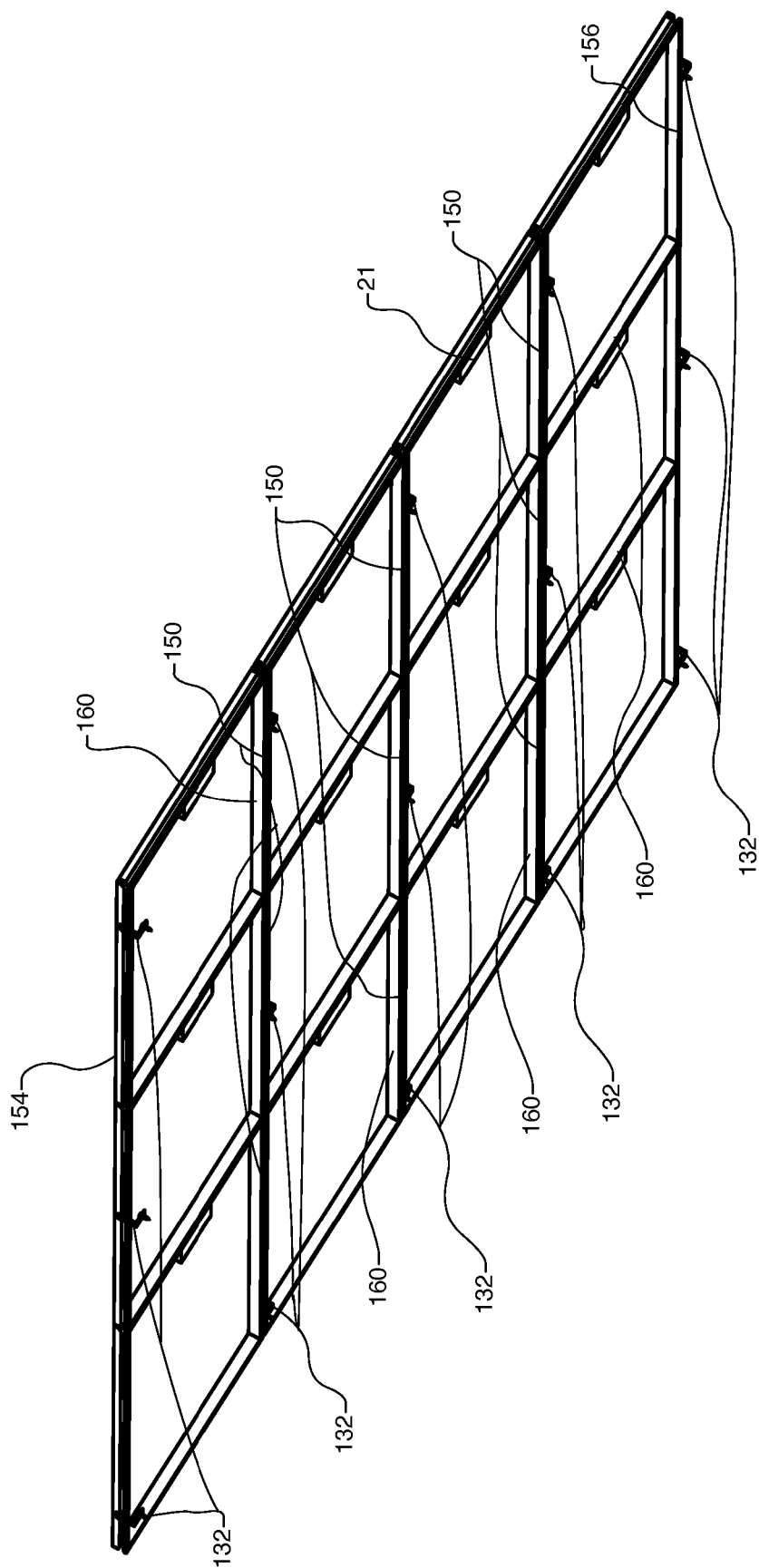


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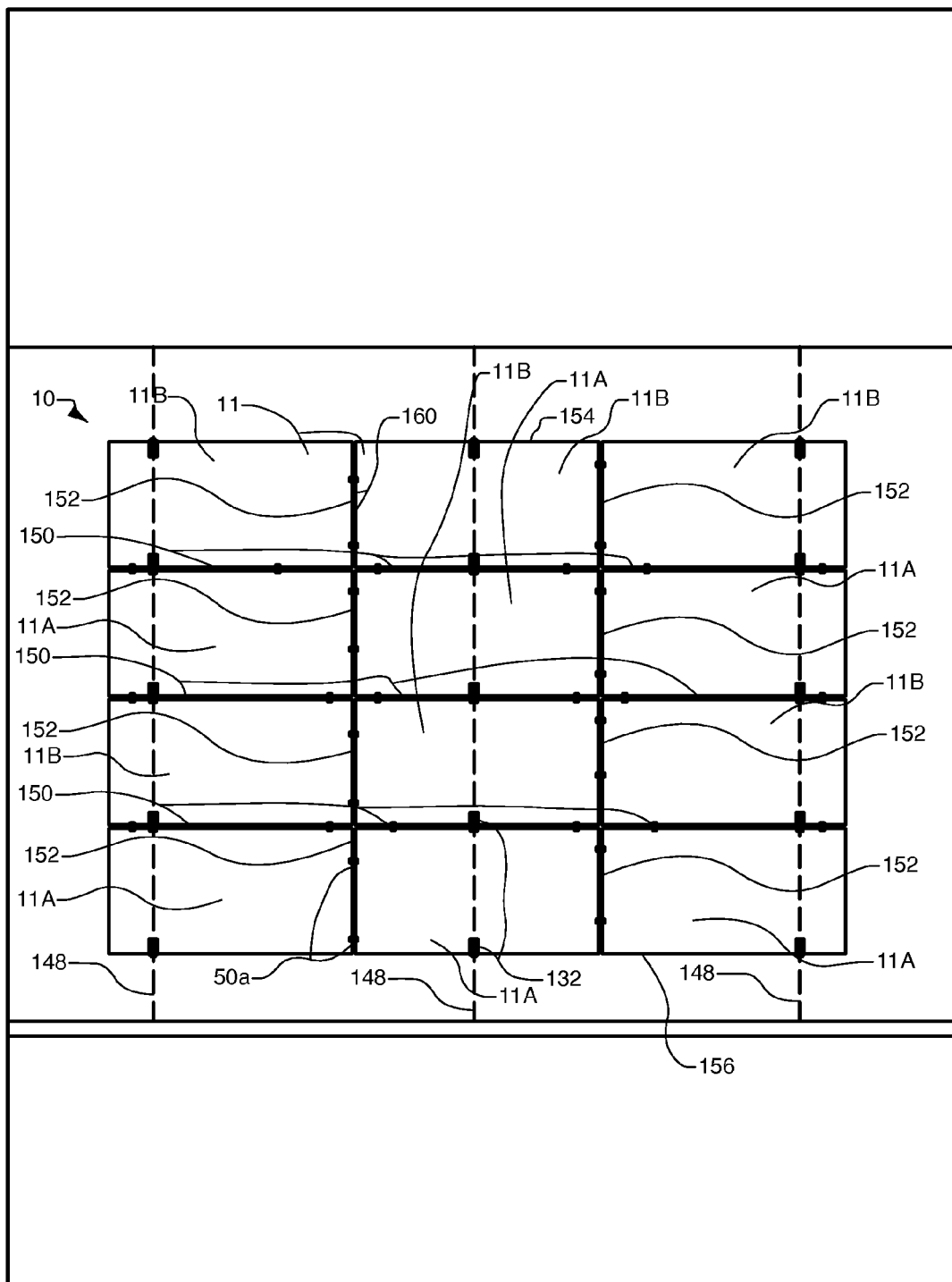


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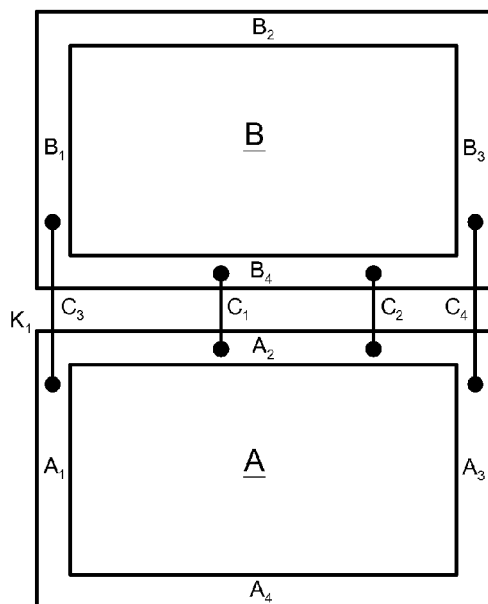


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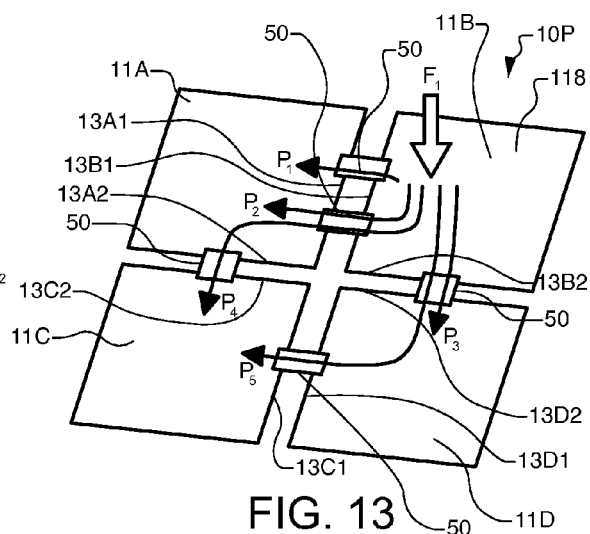


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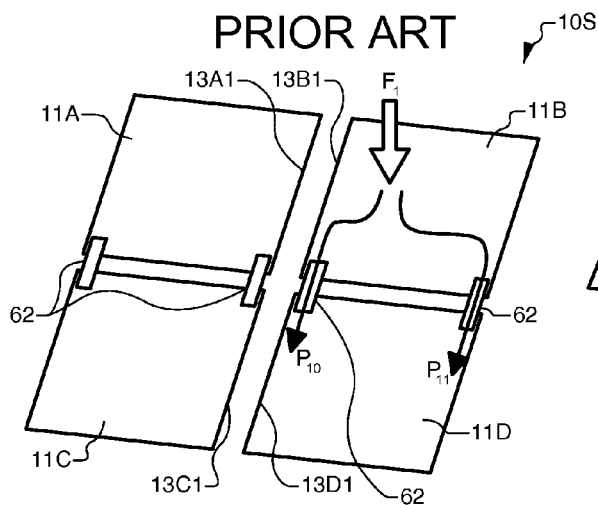


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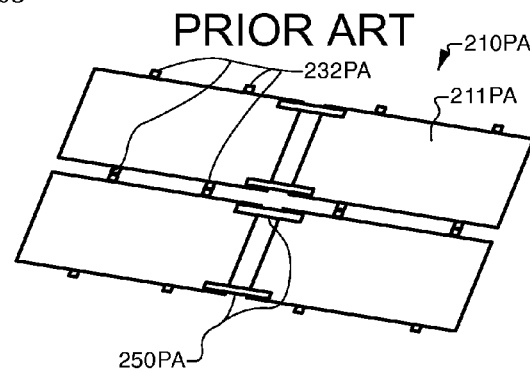


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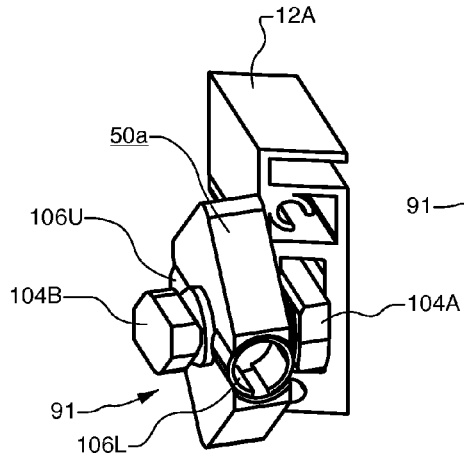


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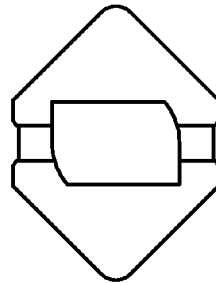


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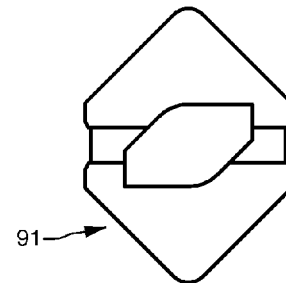


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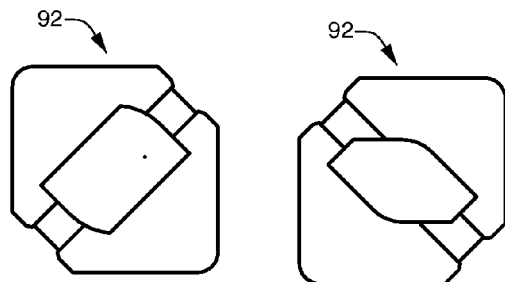


FIG. 21

FIG. 20

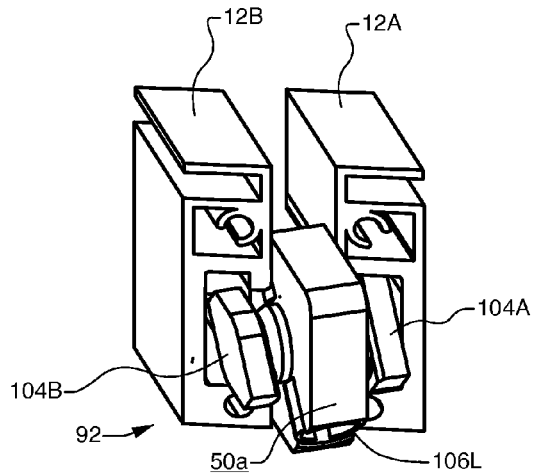


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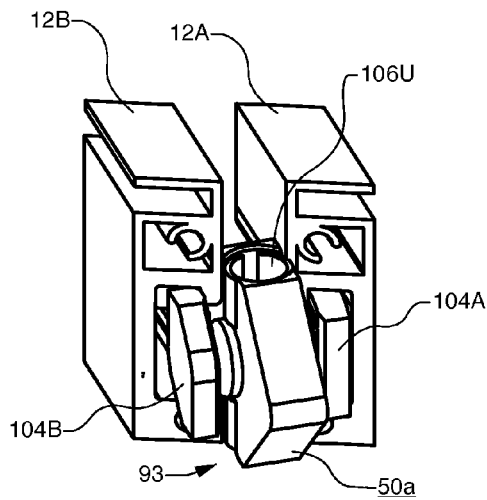


FIG. 22

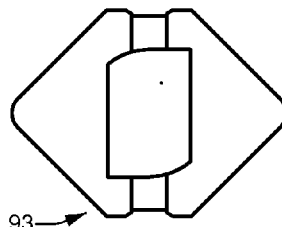


FIG. 23

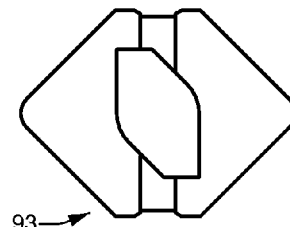


FIG. 24

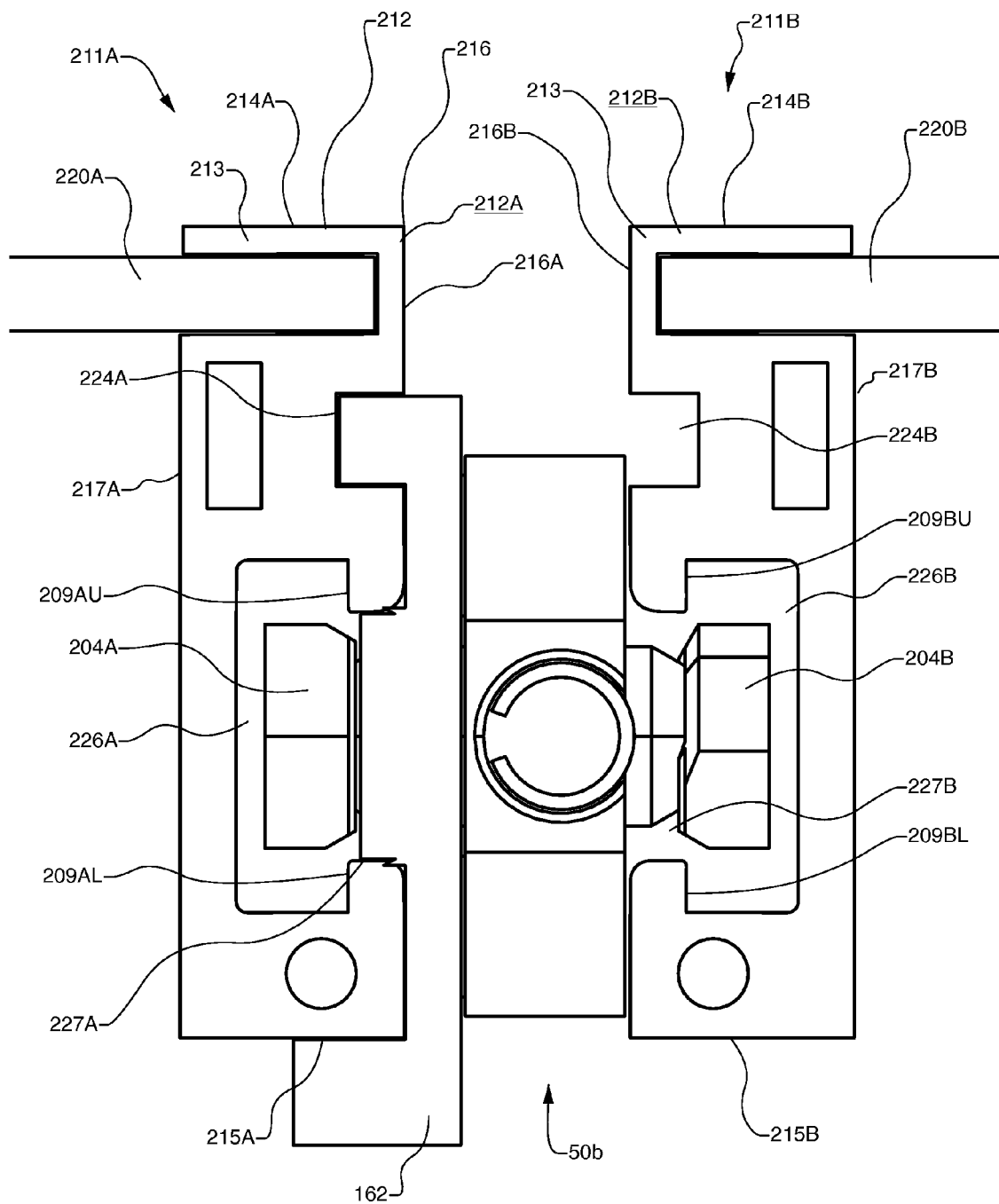


FIG. 25

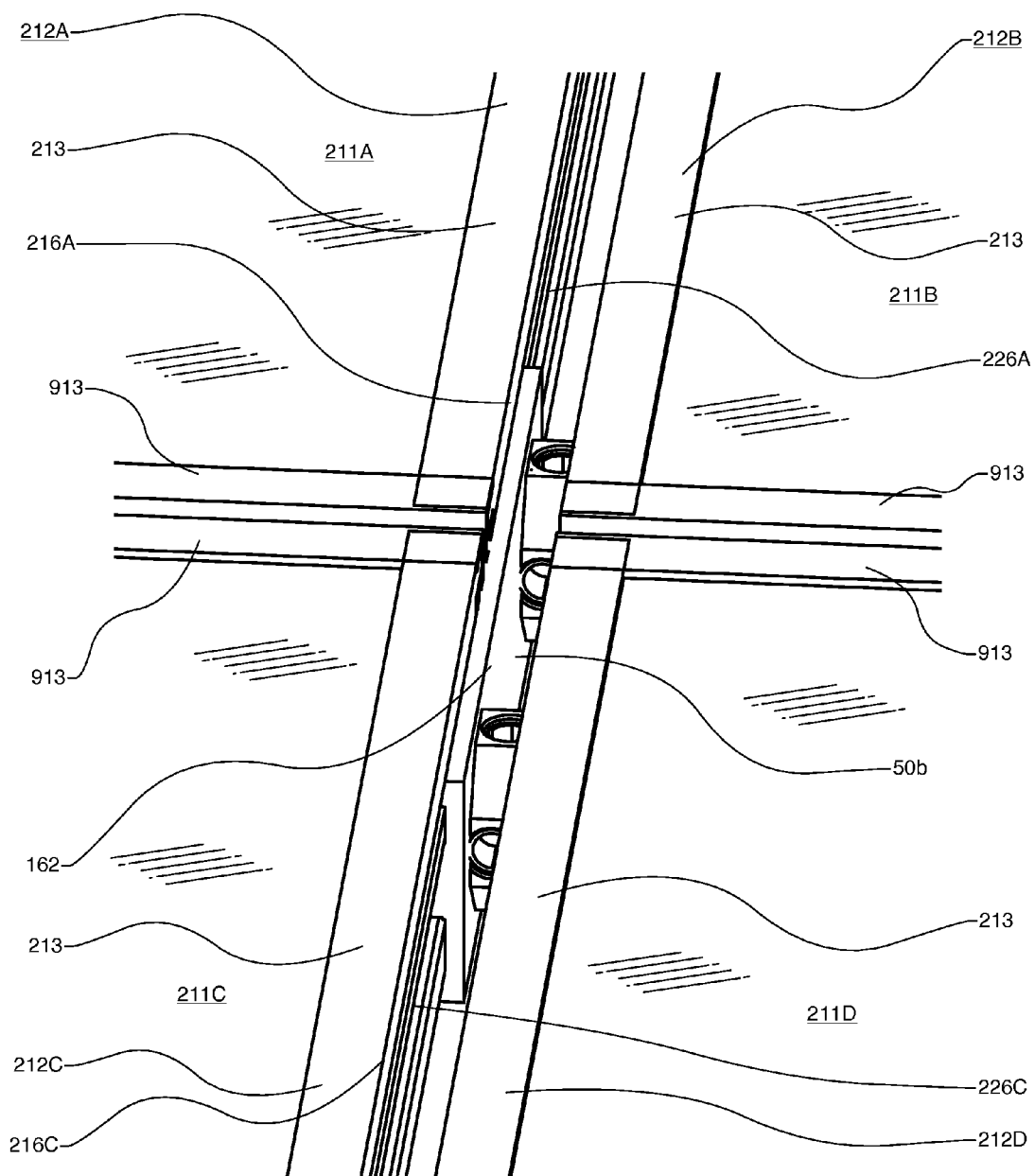


FIG. 26

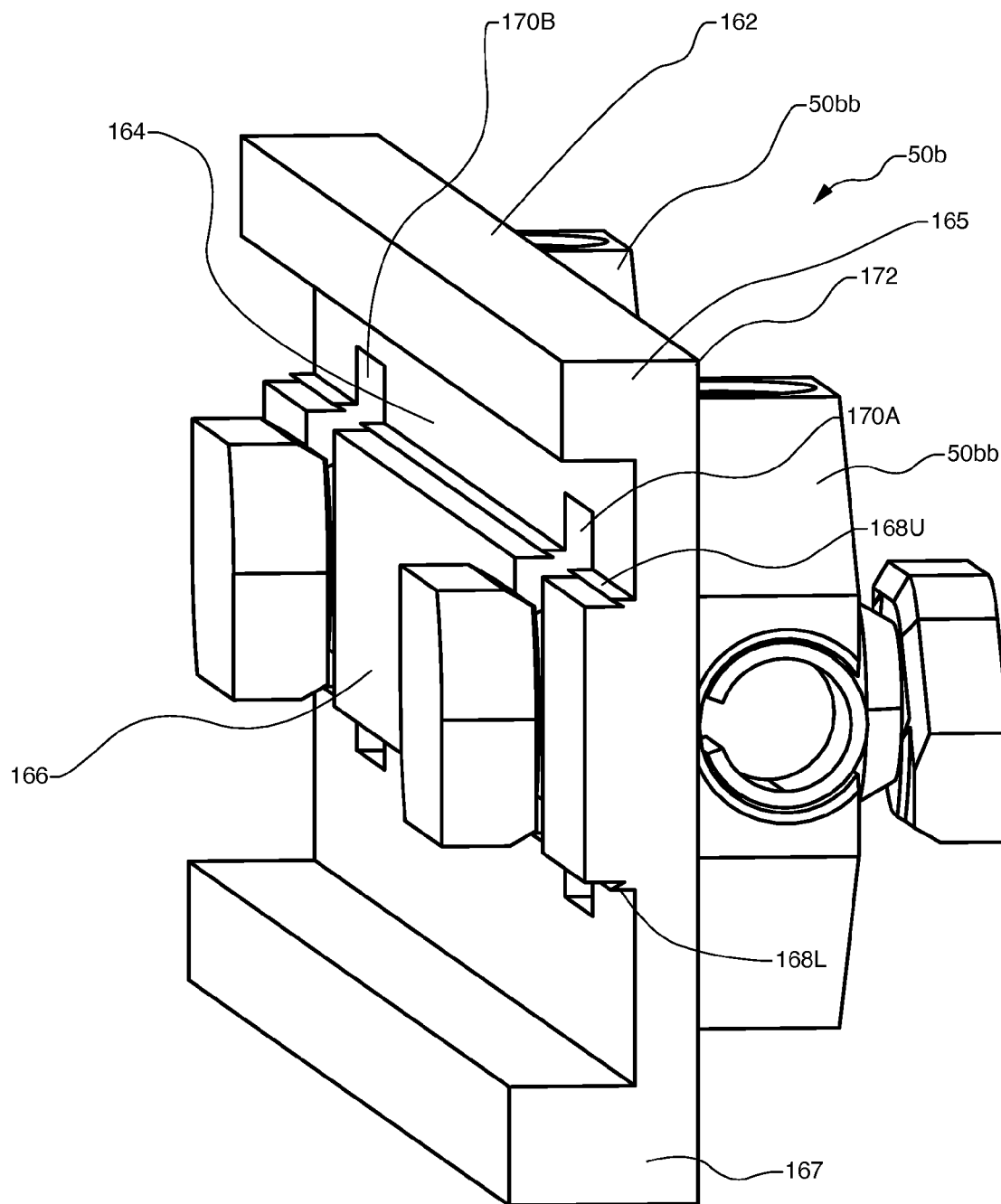


FIG. 27

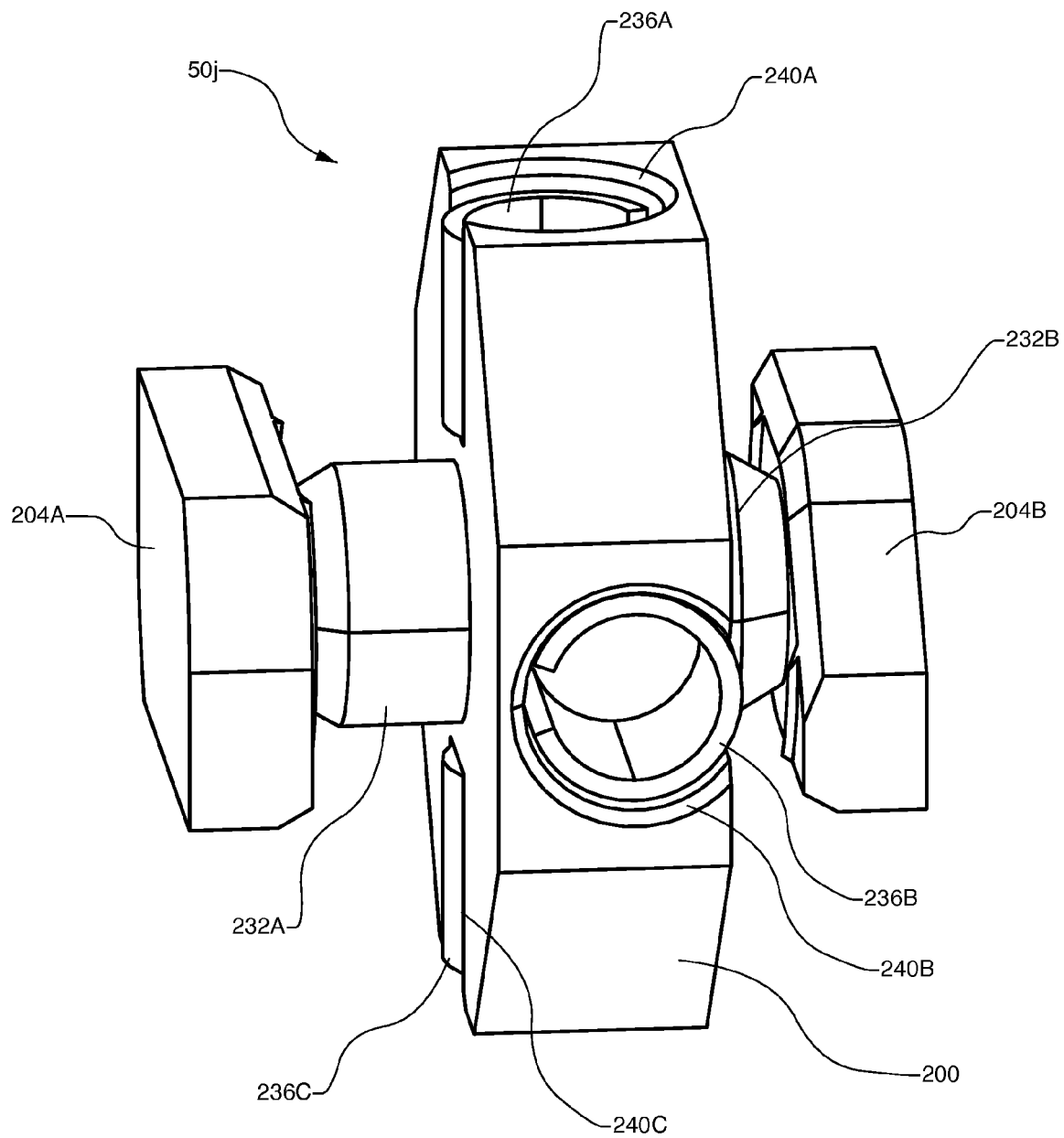


FIG. 28

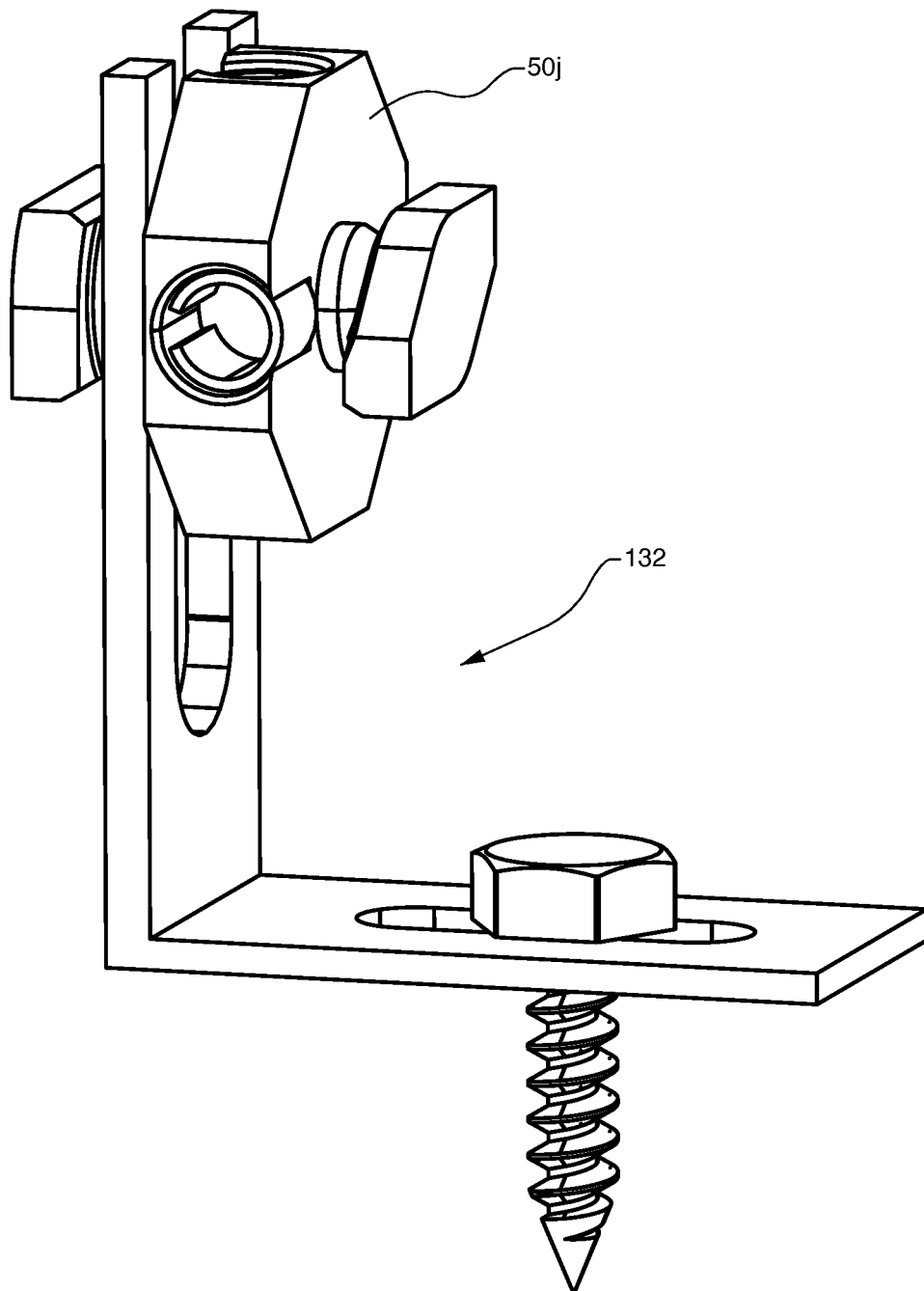


FIG. 29

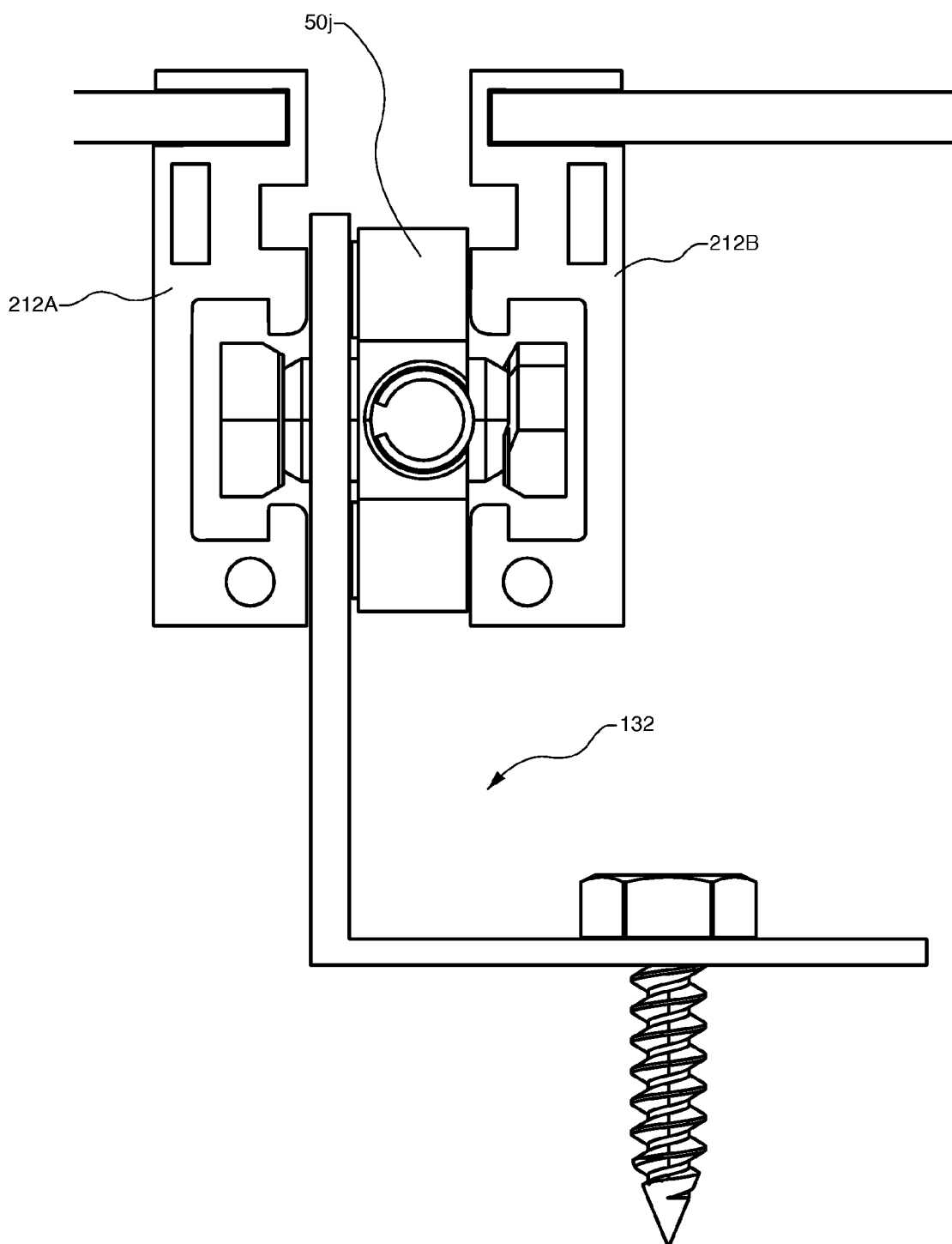


FIG. 30

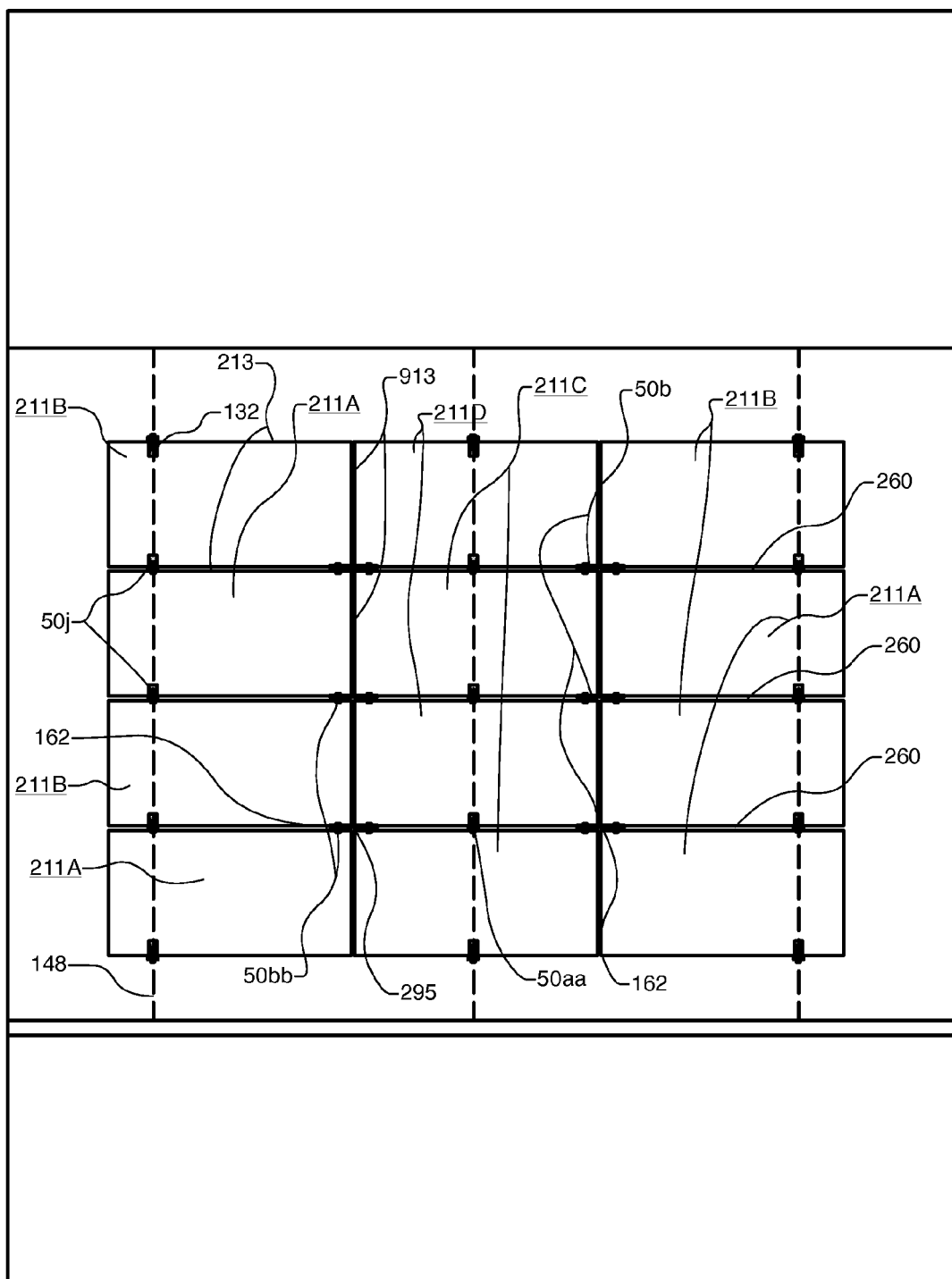


FIG. 31

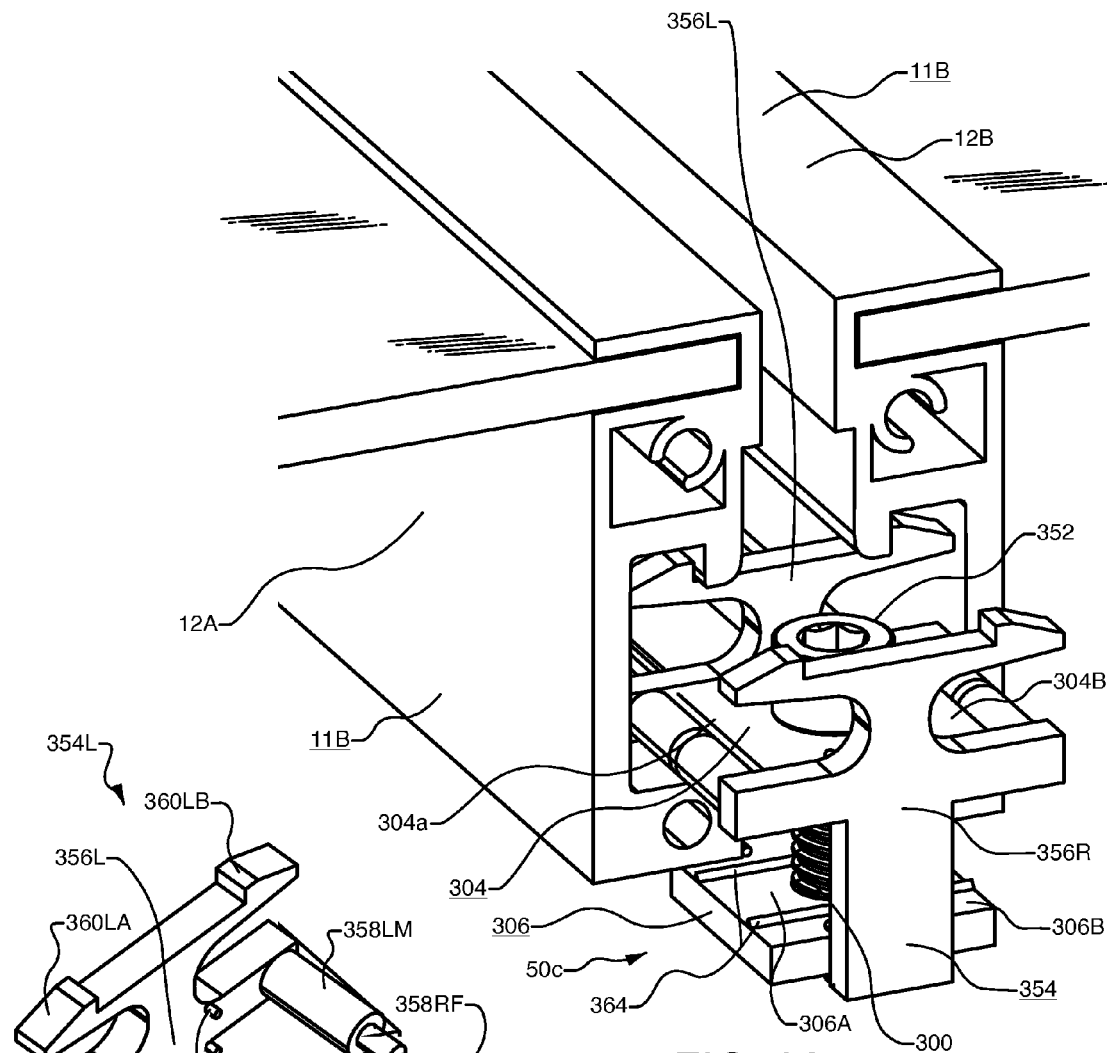


FIG. 32

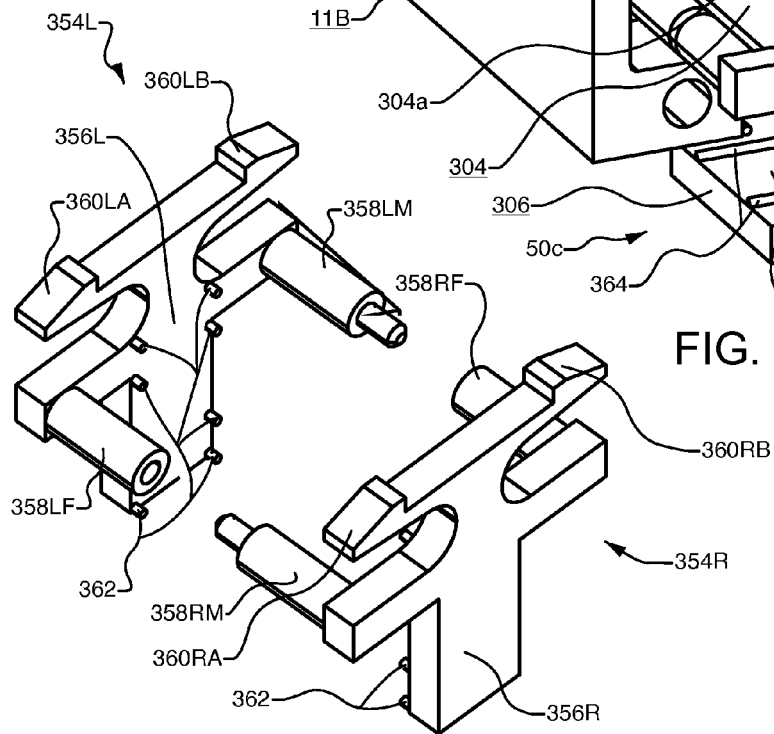


FIG. 33

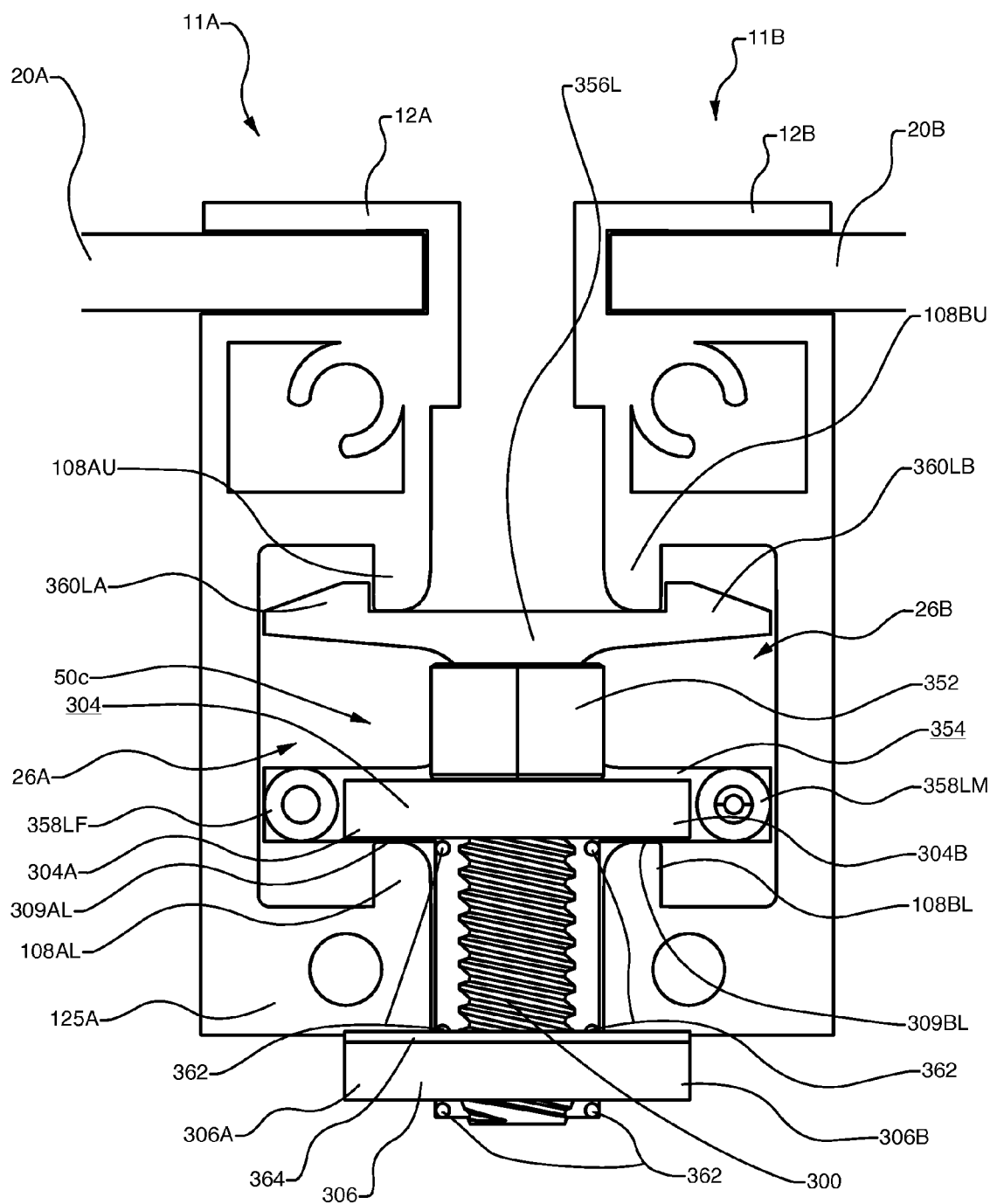


FIG. 34

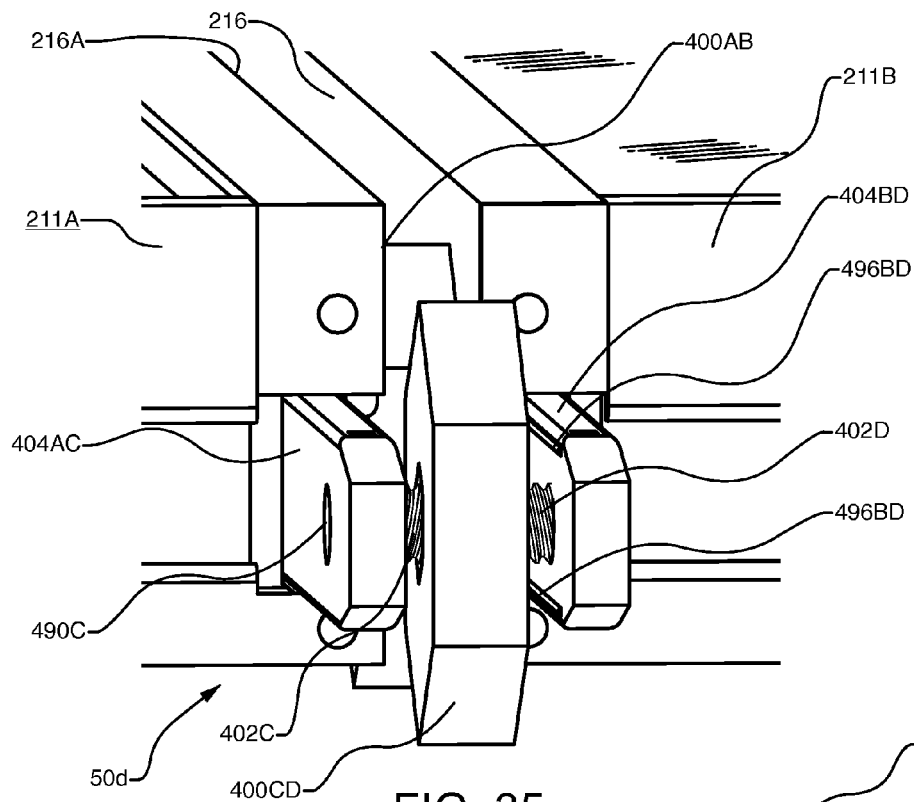


FIG. 35

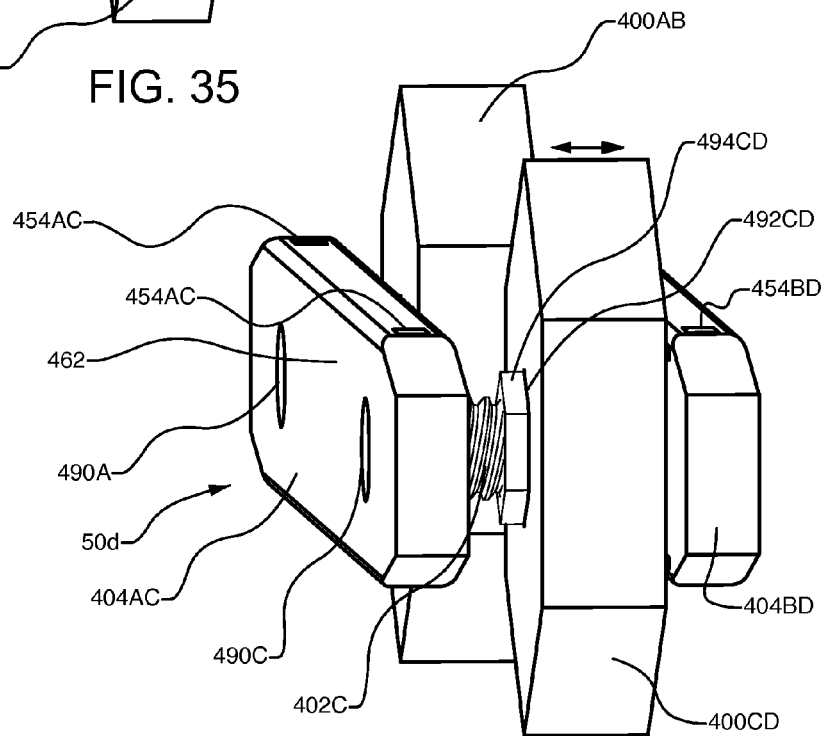


FIG. 36

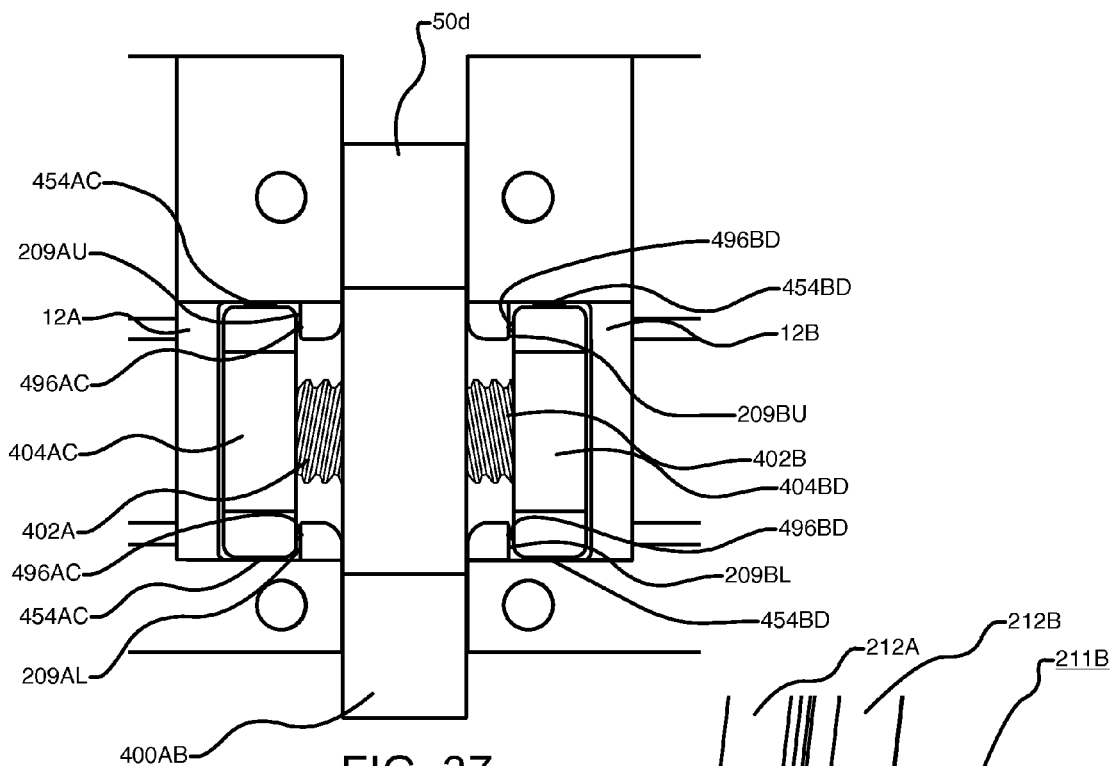


FIG. 37

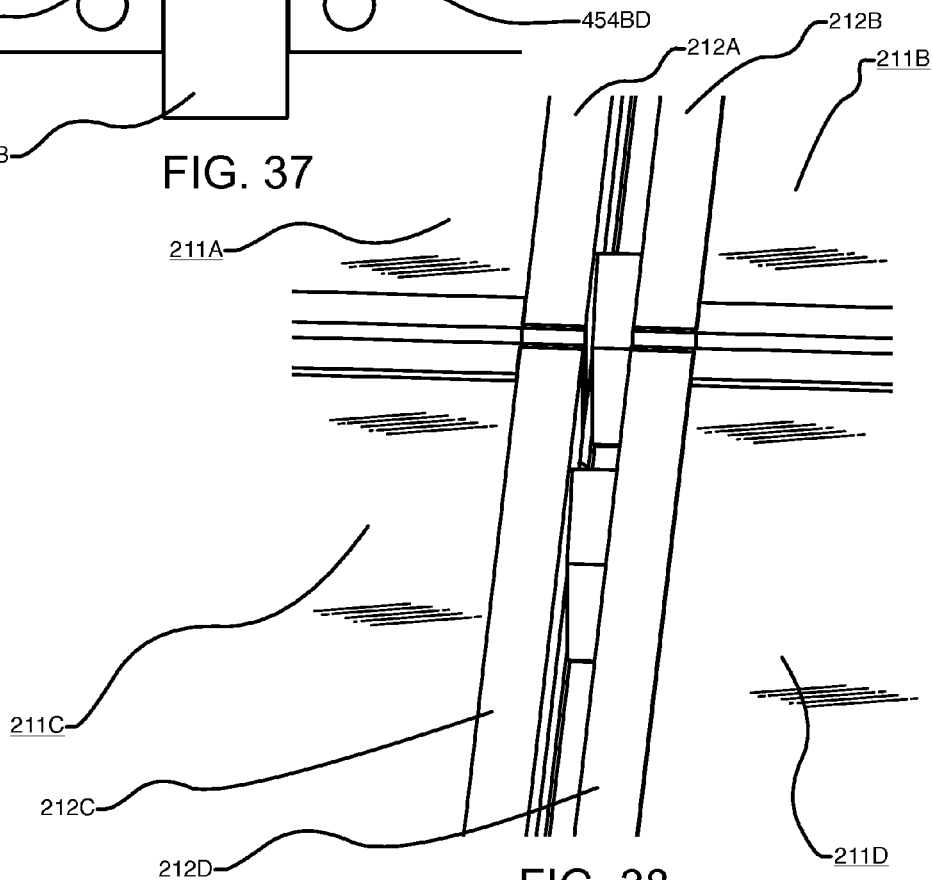


FIG. 38

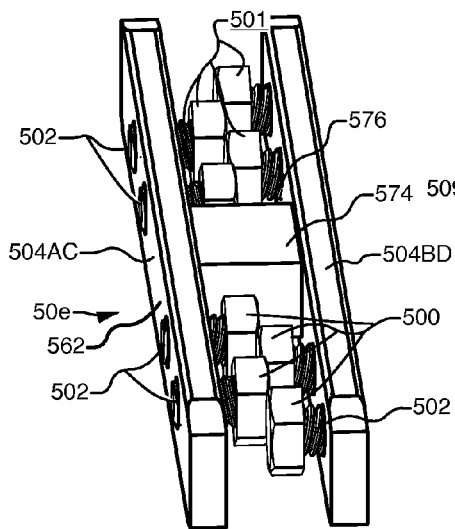


FIG. 39

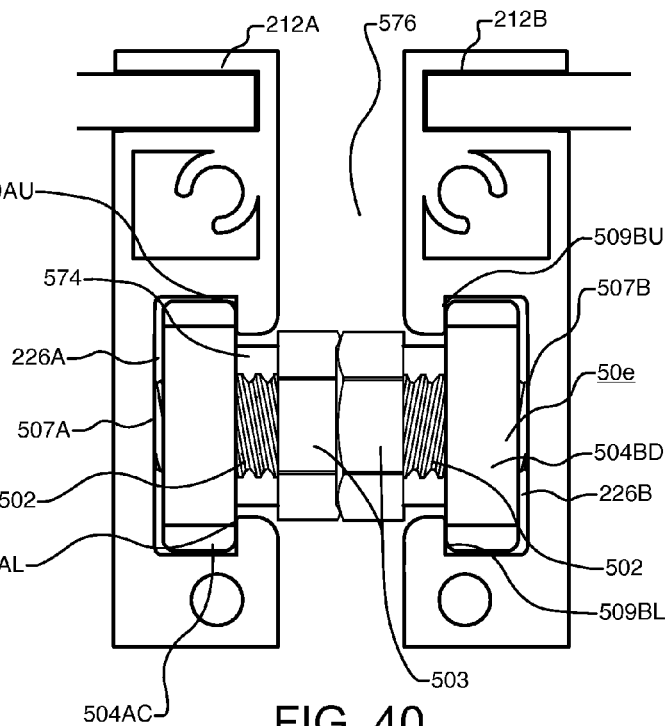


FIG. 40

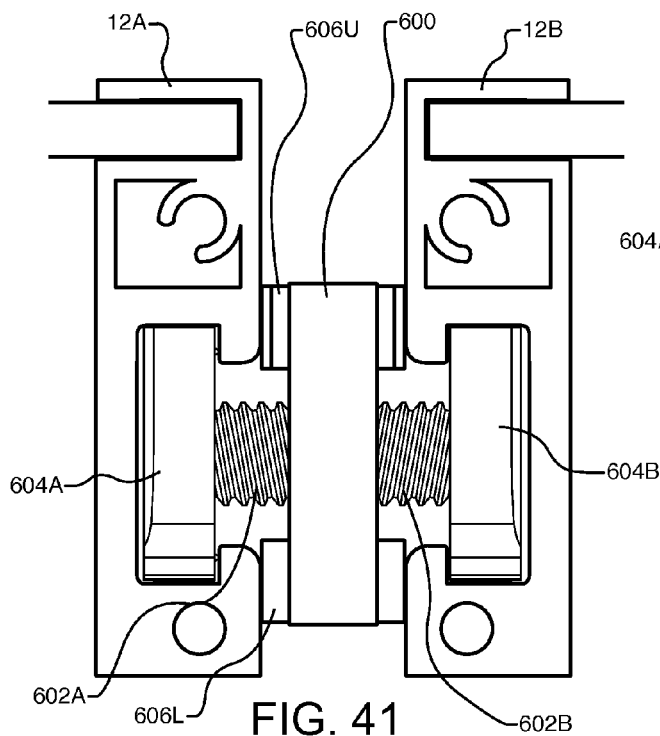


FIG. 41

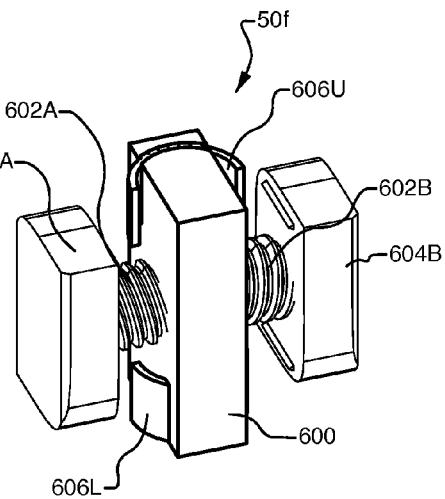


FIG. 42

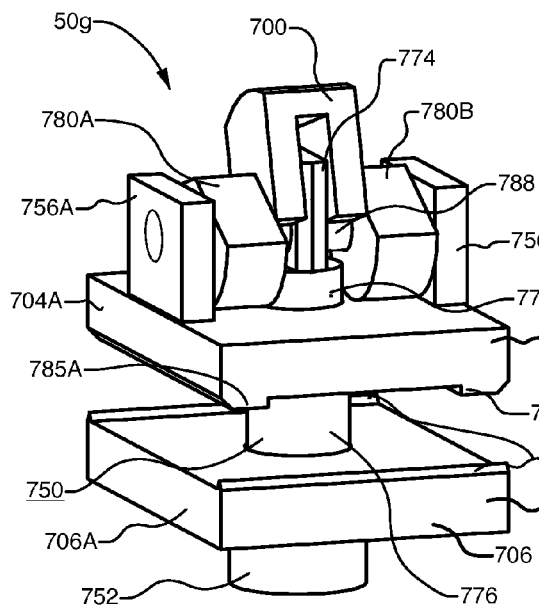


FIG. 43

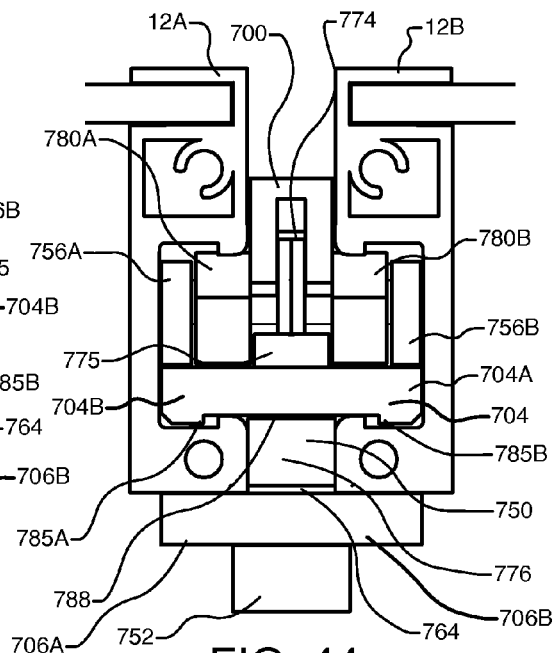


FIG. 44

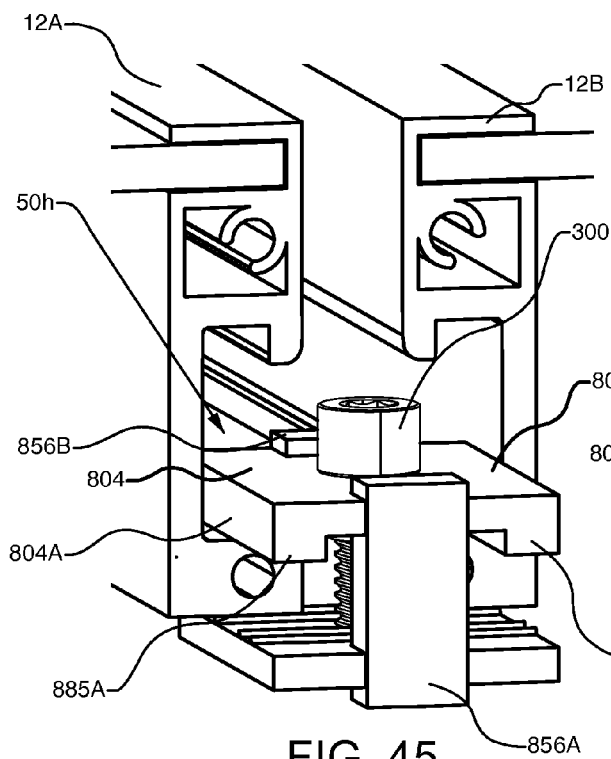


FIG. 45

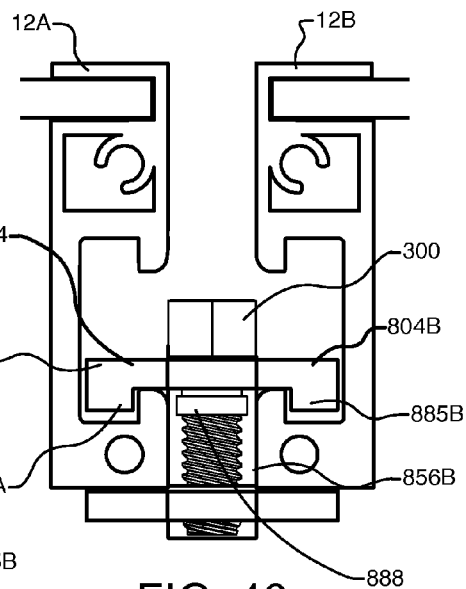
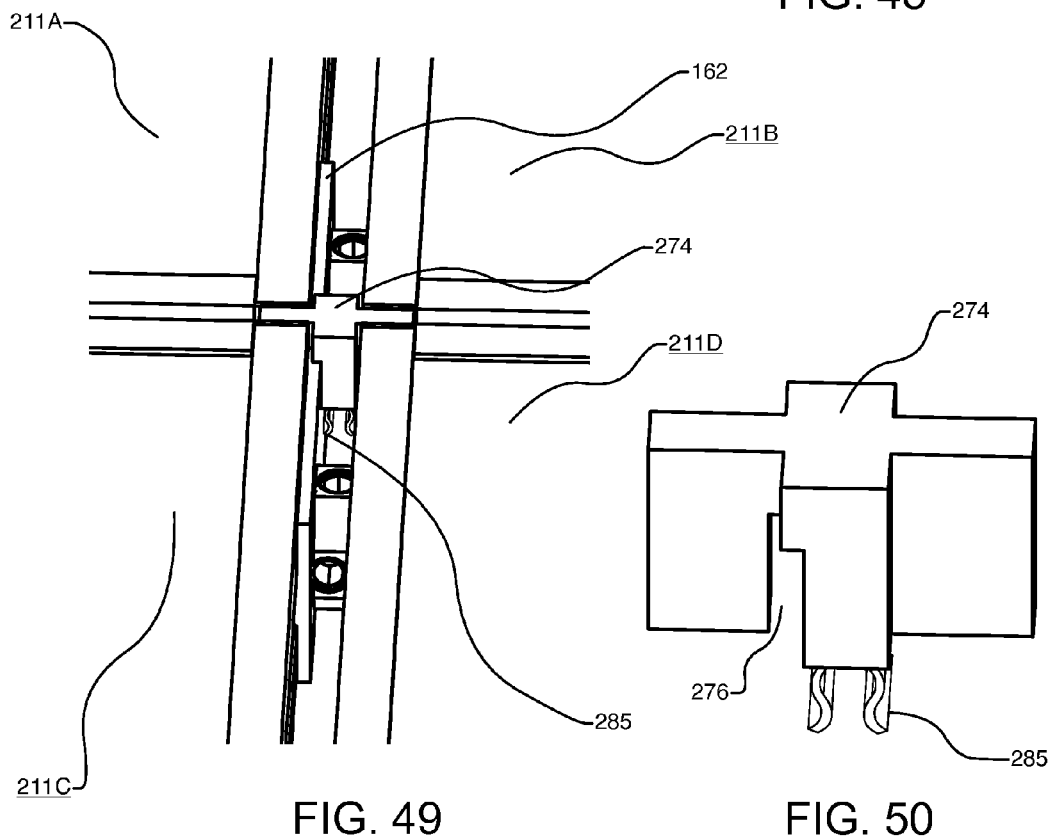
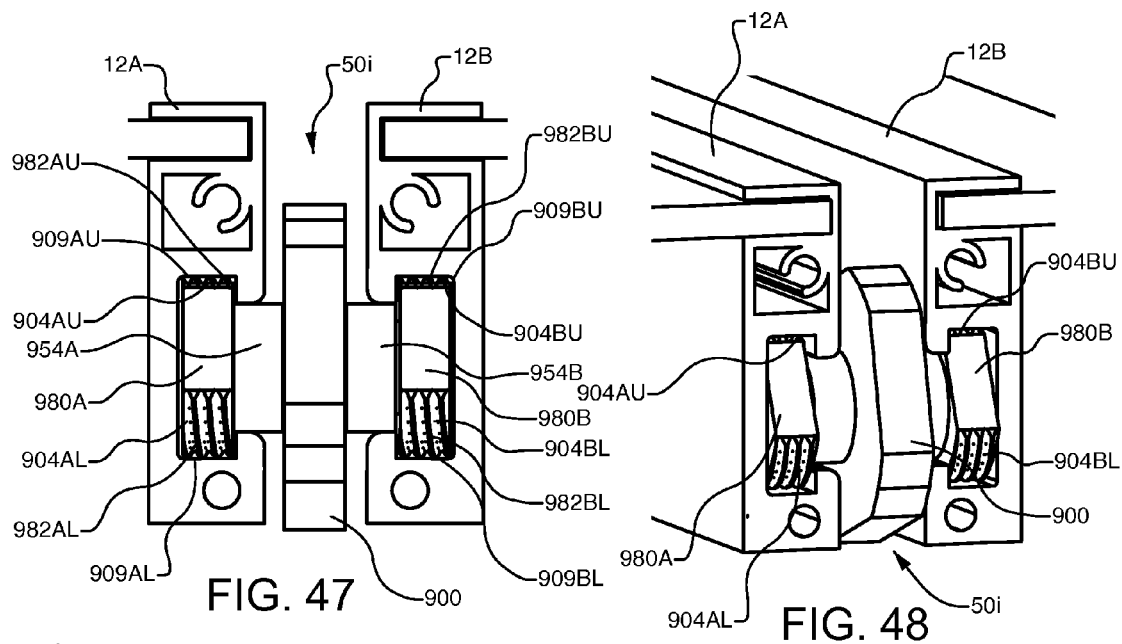


FIG. 46



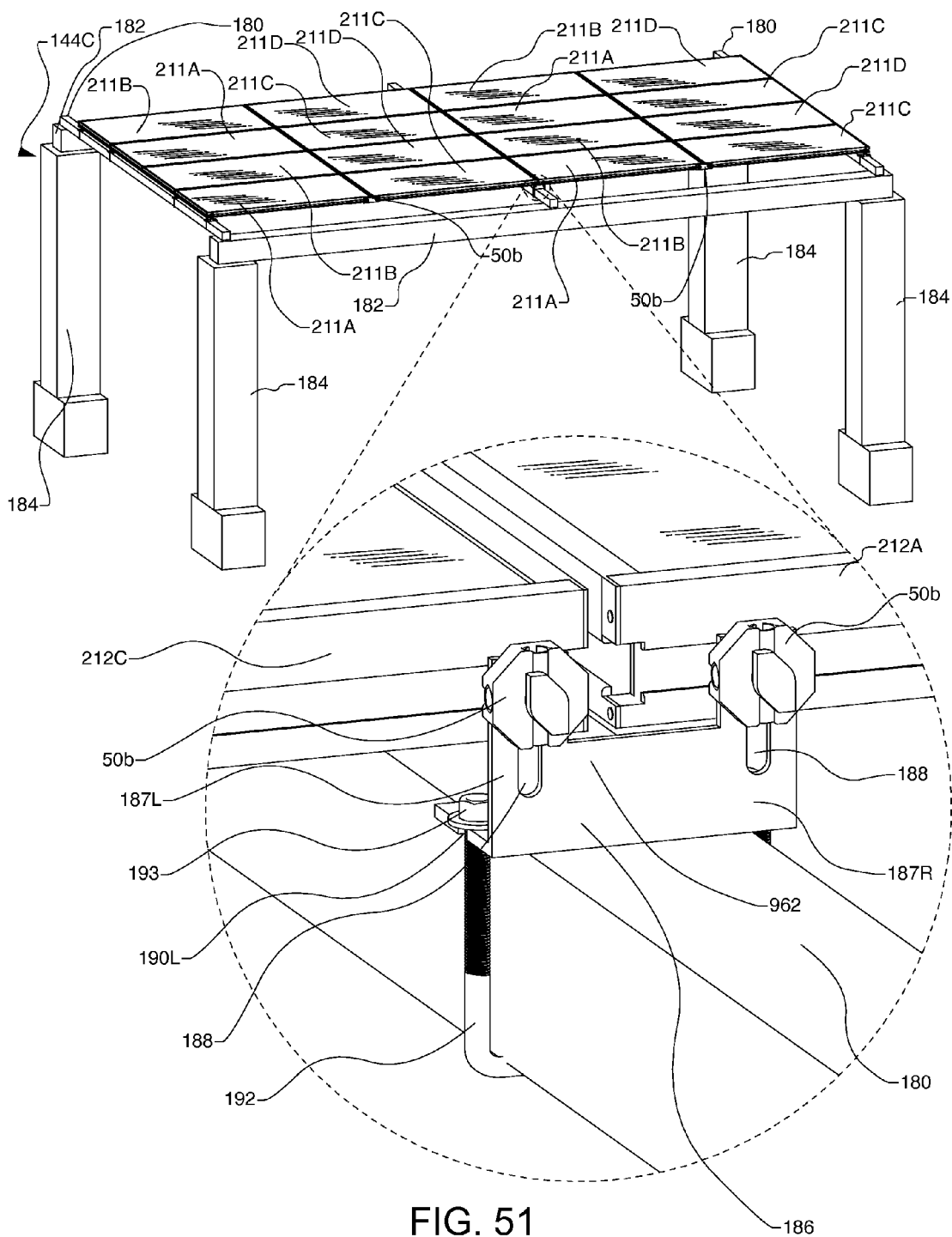


FIG. 51

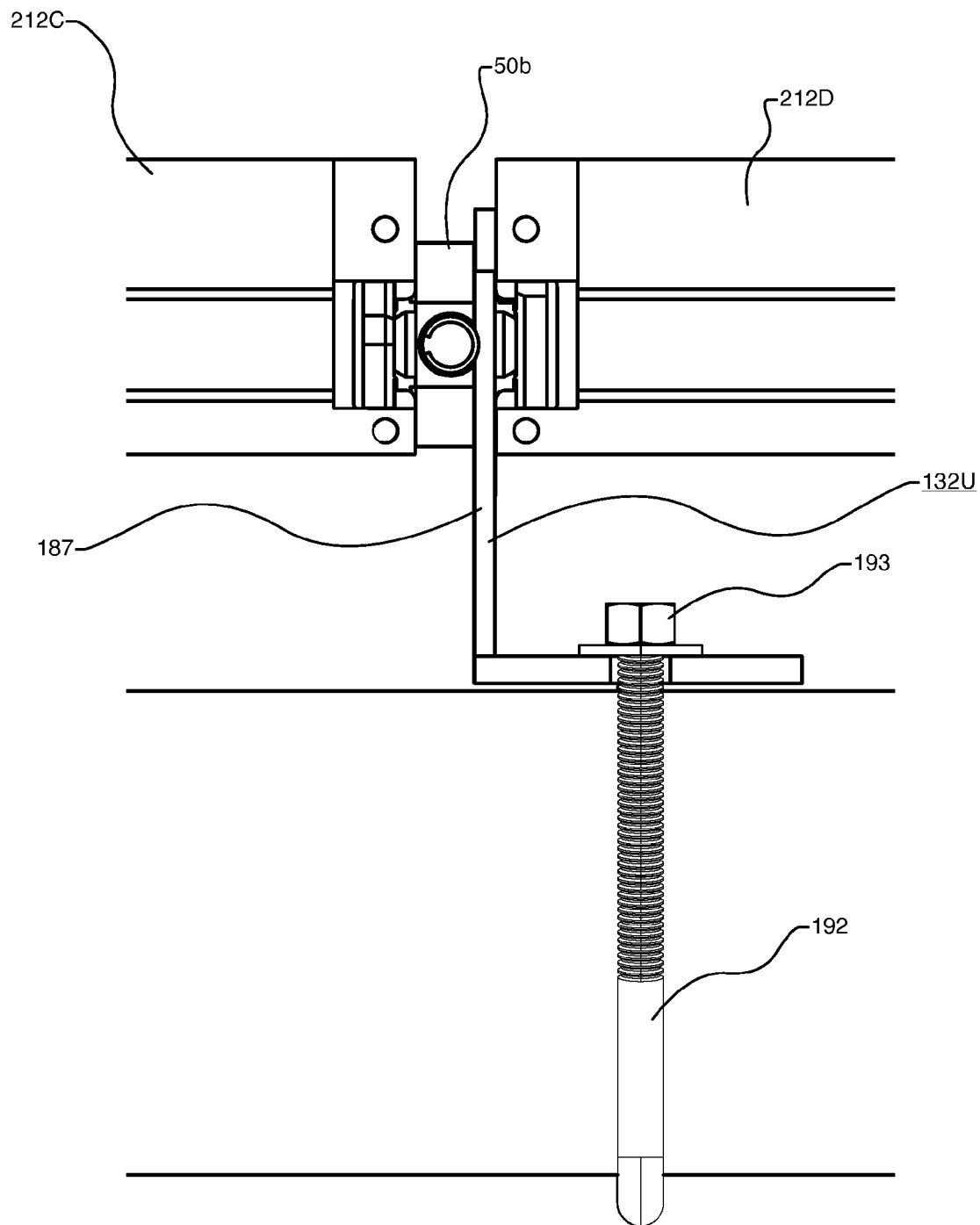
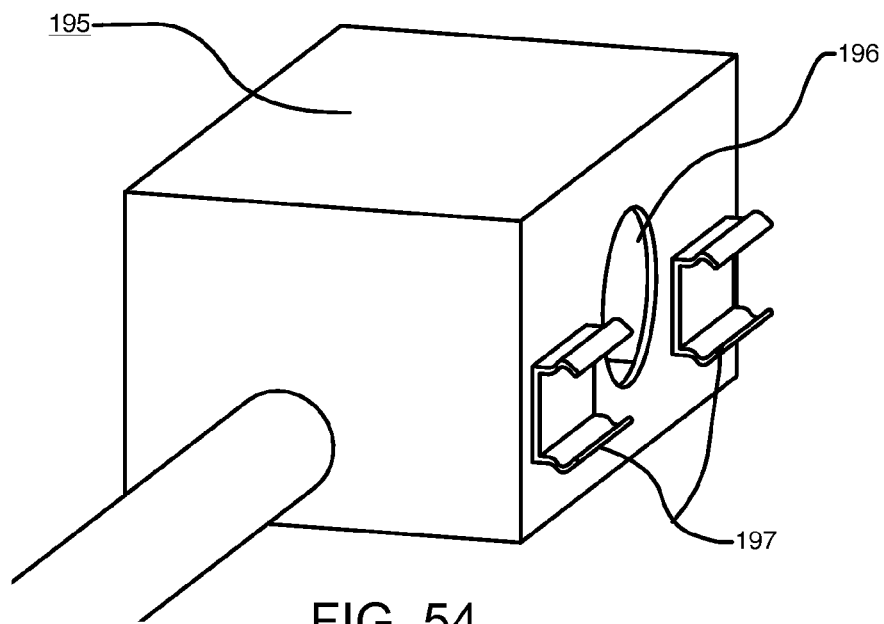
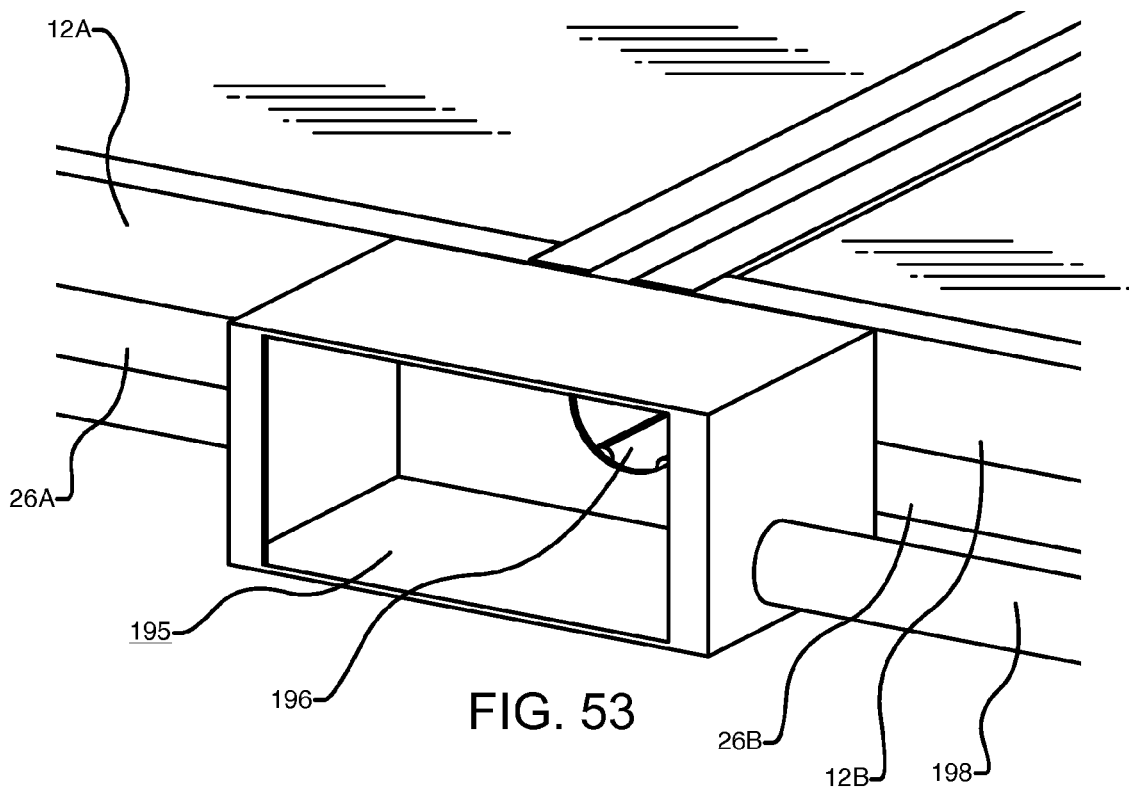


FIG. 52



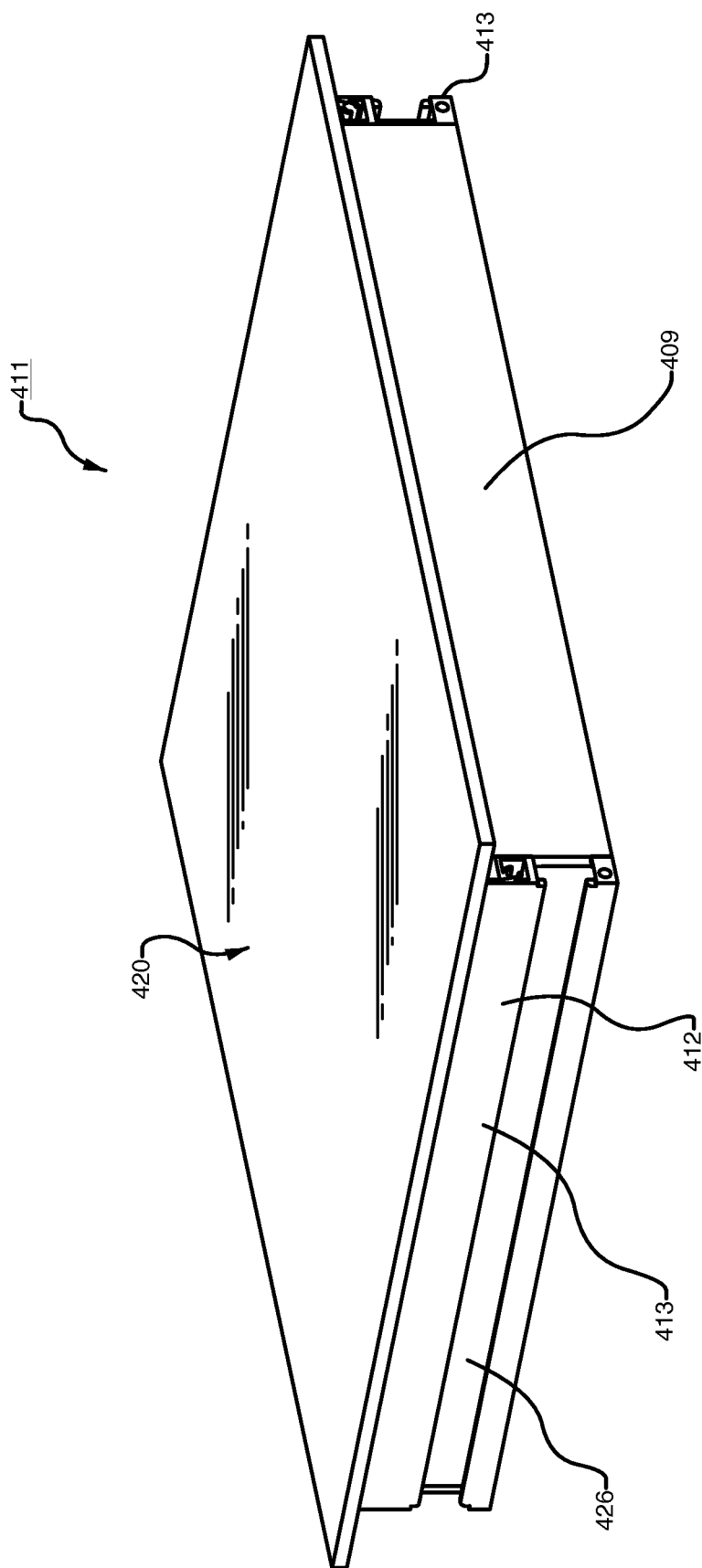


FIG. 55

APPARATUS FOR FORMING AND MOUNTING A PHOTOVOLTAIC ARRAY

CROSS REFERENCES

The present application is a continuation of application Ser. No. 13/351,397, filed Jan. 17, 2012, now abandoned which is a continuation of application Ser. No. 12/594,935 filed Oct. 6, 2009, now U.S. Pat. No. 8,109,048, issued Feb. 7, 2012. The foregoing applications are incorporated by reference in their entirety as if fully set forth herein.

BACKGROUND

Photovoltaic (PV) modules and related mounting hardware are well known and in widespread use. The most common mass-produced PV modules in use today include a laminated portion, or PV laminate, and a frame portion, and are designed specifically to convert light into electricity. The PV laminate portion is for encapsulating solar cells in a substantially flat, weather-tight envelope comprising a laminated construction of various layers including but not limited to glass, clear plastic, encapsulant material (like EVA), active photovoltaic material, interconnecting conductors between solar cells, and a protective backsheet (like PVF film or glass). Photovoltaic laminates are commonly manufactured today in rectilinear shapes like squares, rectangles, triangles, and trapezoids and, due to their fragile nature, are usually completely enclosed by a permanent, substantially rigid, glued-on frame portion which holds and protects the delicate edges of the PV laminate portion and provides a means of supporting the PV laminate and attaching it to other objects without damaging the PV laminate. The combination of the PV laminate portion and the glued-on frame portion is referred to herein as a PV module or framed PV module. The present invention relates to integral frames for standard PV laminates, and to the associated mounting hardware which attaches to the integral frames for the purpose of securing the PV module to a roof or support structure.

U.S. Pat. No. 5,571,338 to Kadonome, et al. discloses a photovoltaic module comprising a photovoltaic panel having a top edge and a bottom edge. An exterior frame structure attached to edges of the photovoltaic panel defines an upwardly open groove extending along at least the top and bottom edges of the panel to direct rain water away from the underside of the panel.

U.S. Pat. No. 7,406,800 to Cinnamon describes an integrated module frame and racking system for a solar panel. The solar panel comprises a plurality of solar modules and a plurality of series couplings or splices (in the form of series couplings) for coupling the plurality of solar modules together. The plurality of splices provide a way to make the connected modules mechanically rigid both during transport to the roof and after mounting for the lifetime of the system, provide wiring connections between modules, provide an electrical grounding path for the modules, provide a way to add modules to the panel, and provide a way to remove or change a defective module. Connector sockets are provided on the sides of the modules to simplify the electrical assembly of modules when the modules are connected together with splices.

U.S. Patent Application 20070074755 by Eberspacher, et al. teaches a photovoltaic module with a rigidizing backplane. A solar cell module includes one or more photovoltaic (PV) cells arranged in a substantially planar fashion. Each PV cell has a front side and a back side. The PV cells are

adapted to produce an electric voltage when light is incident upon the front side. A rigid back plane is attached to the PV cells such that the back plane provides structural support from the back side. The rigid back plane includes a structural component having a plurality of voids.

The foregoing examples of the related art and limitations related therewith are intended to be illustrative and not exclusive. Other limitations of the related art will become apparent to those of skill in the art upon a reading of the specification and a study of the figures.

SUMMARY OF THE INVENTION

The method and apparatus for forming and mounting a photovoltaic (PV) array of this invention provides a PV module framing and coupling system which enables the attachment of PV modules to a roof or other mounting surface without requiring the use of separate structural support members which attach directly to and span between multiple PV modules in a formed PV array. The following embodiments and aspects thereof are described and illustrated in conjunction with systems, apparatus, tools, and methods which are meant to be exemplary and illustrative, not limiting in scope. In various embodiments, one or more of the above-described problems have been reduced or eliminated, while other embodiments are directed to other advantages or improvements.

The inventive apparatus may provide a slidable parallel coupling for securely interlocking the outside surfaces of parallel frame members together in a side to side arrangement, thereby enabling the formation of a PV array with improved structural load distribution. The inventive coupling member may attach to a slot in the frame at substantially any position along the length of the frame thereby enabling the interconnection of adjacent PV modules along both an x and y axis. The inventive apparatus may further provide a rotating portion and locking portion for coupling to frame attachment, mounting brackets for direct connection to a mounting surface, grounding teeth for the automatic creation of a reliable two axis grounding matrix, and a rapid twist-lock engagement means for reliably interlocking and aligning PV modules in the array.

In addition to the exemplary aspects and embodiments described above, further aspects and embodiments will become apparent by reference to the figures and by study of the following detailed descriptions.

BRIEF DESCRIPTION OF THE DRAWINGS

Demonstrative embodiments are illustrated in referenced figures and drawings. It is intended that the embodiments and figures disclosed herein are to be considered illustrative rather than restrictive.

FIG. 1 is a perspective view of a PV module with a hybrid, strut-like frame;

FIG. 2 is a perspective view of a parallel coupling;

FIG. 3 is a cross-section cut through two adjacent PV modules;

FIG. 4 is a perspective view of two adjacent PV modules coupled together;

FIG. 5 is a perspective view of a height adjustable bracket;

FIG. 6 is a cross-section cut through two adjacent PV modules;

FIG. 7 is a perspective view of building with a PV array attached to a roof;

FIG. 8 is a side view of the PV array of FIG. 7 at a larger scale;

FIG. 9 shows a typical prior art PV array;

FIG. 10 is a perspective view of the PV array of FIG. 7 viewed from the back;

FIG. 11 is a cross-section cut through a PV array just above the couplings;

FIG. 12 is a simplified top view of two adjacent rectangular frames;

FIGS. 13-14 show generic PV arrays comprising four PV modules with adjacent frame members;

FIG. 15 shows a prior art strutless PV array;

FIG. 16 is a perspective view of a coupling;

FIGS. 17-18 are front and back side views respectively of a coupling in a first position;

FIG. 19 is a perspective view of a coupling;

FIGS. 20-21 are front and back side views respectively of a coupling in a second position;

FIG. 22 is a perspective view of a coupling;

FIGS. 23-24 are front and back side views respectively of a coupling in third position;

FIGS. 25-31 depict a second embodiment of the present invention;

FIGS. 32-34 depict a third embodiment of the present invention;

FIGS. 35-38 depict a fourth embodiment of the present invention;

FIGS. 39-40 are a perspective view and a cross section cut between two interlocked PV modules;

FIGS. 41-42 are a cross section cut between two interlocked PV modules and a perspective view of a coupling;

FIGS. 43-44 are a perspective view and a cross section cut between two interlocked PV modules;

FIGS. 45-46 are a perspective view and a cross section cut between two interlocked PV modules;

FIGS. 47-48 are a cross section cut between two interlocked PV modules and a perspective view respectively for an alternate embodiment;

FIGS. 49-50 depict a further alternate embodiment;

FIGS. 51-52 depict a further alternate embodiment as installed on an open canopy structure;

FIGS. 53-54 show an alternate embodiment of a PV array with a snap-in conduit box; and

FIG. 55 depicts a perspective view of a further alternate embodiment of a PV module.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIGS. 1 through 55, wherein like reference numerals refer to like components in the various views, there is illustrated therein a new and improved framing and mounting system for photovoltaic arrays, generally denominated 10 herein. While various terms may have their ordinary meaning or particular meaning in the art, for ease of understanding there is provided herein, both below and at other locations in this specification, a non-limiting explanation as to the minimum scope intended for understanding of the present specification. Terms may be in singular or plural or any tense while retaining the same general meaning. Photovoltaic is abbreviated as "PV". PV laminate refers to an encapsulated group of solar cells. Frame refers to a group of frame members (typically four for a rectangular-shaped PV module) which support and provide rigidity to a PV laminate. PV module refers to a single, one-piece, individually deployable electricity generating device comprising a PV laminate, a frame, and at least two output wires. A PV

array refers to a group of PV modules which are deployed together and are a part of the same electricity generating system. A mounting rail or strut is a structural member which connects to the bottom of a PV module via the use of a separate fastener (such as a coupling, bolt, etc.) and which serves to mechanically link two or more PV modules together, thereby providing structural support for the modules and also providing a means for connection to a mounting surface.

First Embodiment—Structure

FIGS. 1-24 depict a first embodiment of the present invention. FIG. 1 provides a perspective view of a photovoltaic or PV module 11 with a hybrid, strut-like frame 12. Each PV module is made of substantially identical construction. As is typical in the art, frame 12 comprises four frame members 13 which are assembled around PV laminate 20 and secured by optional adhesive between frame members 13 and laminate 20 and frame screws 18U, 18L at the corners. The complete PV module 11 is typically assembled in this way at a PV module manufacturing facility; then a plurality of one-piece PV module assemblies 11 are transported to a particular job site and mounted to a building or other structure to form a PV array 10. In other embodiments we contemplate the assembly of frames 12 around PV laminates 20 at the final installed location. Thus, the exact location of the manufacturing and assembly steps is non-critical with regards to proper implementation of the present invention.

Hybrid, strut-like frame 12 may include substantially similar construction on all four sides of PV module 11. Top surface 14 of frame 12 is the surface which faces the same direction as the cells (not shown) in PV laminate 20. Frame outside surface 16 comprises a multifunction female channel portion or slot 26 for the purpose of interlocking PV modules 11 together and connecting to a roof or other mounting surface as will be discussed below. Frames 12 as shown here have the corners cut to allow for a typical butt joint. In other embodiments the frames are joined at the corners via a mitre joint. Furthermore, any of the typical methods for joining framing members at the corners is applicable and covered in the scope of the present invention. Corners may also be fashioned to allow insertion of couplings from the corner and to allow smaller couplings to slide around the corner in a formed array. PV module 11 further comprises positive 22pos and negative 22neg output cables with positive 24pos and negative 24neg plugs as are typical in the art. In other embodiments multi-conductor cables are utilized. Output cables 22pos, 22neg originate in a rear-mounted electrical box 21.

FIG. 2 depicts a perspective view of an interlocking device or parallel coupling 50a which may be utilized to interlock the outside surfaces 16 of two adjacent PV module frames 12 via a twist-lock action. This first embodiment contemplates a one-piece parallel coupling 50a comprising a rotating portion 100 with shaft portions 102A, 102B protruding from each side. The end of shaft portion 102A comprises a first key or locking portion 104A, and the end of shaft portion 102B comprises a second key or locking portion 104B. Both locking portions 104A, 104B rotate with the shaft portions 102A, 102B upon rotation of rotating portion 100 with a wrench.

Rotating portion 100 further comprises an optional top spring 106U and bottom spring 106L to help account for variations in material and assembly tolerances, to mitigate thermal expansion and contraction variance, and to provide

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a force which resists the unlocking of two interlocked PV modules 11. Bores 110U and 110L (not viewable here) in rotating portion 100 are provided to house and structurally support springs 106U, 106L respectively. Springs 106U, 106L are shown here as cylindrical springs and may be made from spring steel or other suitable spring material. Other embodiments contemplate springs of other types and shapes, and still other embodiments provide coupling 50a without springs since frame 12 under compression provides some spring force. For example, disc washers, wave washers, star washers, finger springs, spiral springs, polyurethane springs, and others are all suitable for use with the present embodiment under discussion. Rotating portion 100 comprises four flat faces 116 so that rotating portion 100 can be easily turned with a typical wrench from above. One skilled in the art will recognize that the number of flat faces could vary and rotating portion 100 could be simply rounded, slotted, bored, or knurled depending on the type of wrench which is utilized. Shaft portions 102A, 102B further comprise optional reduced diameter portions 114A, 114B to help guide and hold a free PV module 11 which is being moved into position for coupling. Rotating portion 100 (except for springs 106U, 106L), shaft portions 102A, 102B, and locking portions 104A, 104B may be machined from a single piece of solid metal, such as steel or aluminum. In another embodiment rotating portion 100 may be made of a lightweight material such as plastic. However, one skilled in the art will recognize that multiple components could be assembled together and various materials could be used to form the various portions of coupling 50a as described herein.

Expanding the discussion now to further include FIG. 3, which depicts a cross-section cut through two adjacent PV modules 11A, 11B which are coupled together with a coupling 50a, it can be seen that first locking portion 104A may be specially shaped to be the first of the two locking portions 104A, 104B which is inserted into a first slot 26A of PV module 11A. Locking portion 104A may be provided with curved surfaces 118U, 118L on opposite corners which allow locking portion 104A to be rotated in a clockwise manner inside of slot 26A until locking portion stops 120AU, 120AL contact upper 122AU and lower 122AL inside surfaces of slot 26A respectively. With reference to FIGS. 16-24, which will be discussed in more detail below, one skilled in the art will recognize that the width of locking portion 104A is slightly less than the height A of openings 27A, 27B in slots 26A, 26B, while the length is approximately equal to the height B inside of slot 26A. Therefore locking portion 104A may be inserted when it is oriented in a first position 91 and captured behind male features or flanges 108AU, 108AL when it is rotated clockwise. After approximately 90 degrees of clockwise rotation, when locking portion stops 120AU, 120AL are reached coupling 50a is said to be in a third position 93 (see below for discussion of an intermediate second position 92).

Accordingly, second locking portion 104B may be specially shaped to be the second of the two locking portions 104B, 104A to be inserted into a second slot 26B in PV module 11B. This first embodiment contemplates a shape for locking portion 104B which is capable of passing between male features or flanges 108BU and 108BL for approximately the first 45 degrees of clockwise rotation of coupling 50a. Thus the intermediate position of approximately 45 degrees of clockwise rotation is said to be the second position 92. The shape of locking portion 104B is similar to locking portion 104A except that material has been removed in the clearance zones 124U, 124L directly opposite curved

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surfaces 118U, 118L on locking portion 104A. Thus, orientation of coupling 50a in first position 91 and insertion of locking portion 104A into slot 26A followed by a rotation to second position 92 results in locking portion 104A being captured by slot 26A and locking portion 104B being correctly oriented for insertion into slot 26B. Furthermore, insertion of locking portion 104B into slot 26B followed by an additional rotation of approximately 45 degrees clockwise to third position 93 results in locking portion 104B being captured by slot 26B. Rotation ceases when locking portion stops 120AU, 120AL contact surfaces 122AU, 122AL inside slot 26A and locking portion stops 120BU, 120BL contact surfaces 122BU, 122BL inside slot 26B, and at this point the outside surfaces 16A and 16B of PV modules 11A and 11B are said to be coupled or interlocked together (these two terms are used interchangeably throughout this document). Other embodiments contemplate a number of variations on the locking portions 104A, 104B and the slots 26A, 26B, all of which are within the scope of the present invention. For example, some embodiments may utilize locking portions 104A, 104B which are identical in shape but simply rotated at different angles from each other relative to shaft portions 102A, 102B. Such embodiments are still capable of providing a solid interlock but do not allow removal of a single module from the middle of a completely installed PV array 10 since first position 91 can only be reached when locking portion 104B is not inside slot 26B. Other embodiments include locking portions which are shaped for different angles of rotation other than 45 and 90 as discussed above, while others have locking portions which are shaped for counter-clockwise rotation.

Locking portions 104A, 104B further comprise tapered surfaces 105AU, 105AL, 105BU, and 105BL to guide them into position as coupling 50a is rotated and raised teeth 112AU, 112AL, 112BU, and 112BL for cutting into frame 12 and ensuring solid electrical ground contact between two adjacent PV modules 11 when they are coupled together. Teeth 112AU, 112AL, 112BU, 112BL also provide structural support by counteracting forces which tend to slide coupling 50a lengthwise in slots 26A, 26B. In other embodiments teeth 112 are provided in different locations than those shown here, and in still other embodiments teeth 112 are replaced by a separate grounding washer, such as a star washer, which is positioned between a portion of coupling 50a and frame 12.

As shown in FIG. 3, slots 26A, 26B from two adjacent, interlocked modules 11A, 11B comprise openings 27A, 27B which allow insertion of couplings 50a in a direction which may be substantially parallel with the plane of laminates 20A, 20B and substantially perpendicular with outside surfaces 16A, 16B. Flanges 108AU, 108AL, 108BU, 108BL, which are located near openings 27A, 27B create (by virtue of their position) inside surfaces 109AU, 109AL, 109BU, 109BL of slots 26A, 26B which are available for use by couplings 50a and brackets 132 (see below) as a bearing surface. Inside surfaces are shown here as being substantially perpendicular to PV laminate 20. However, other embodiments provide sloped and curved surfaces 109AU, 109AL, 109BU, 109BL.

FIG. 3 further reveals frame inside surfaces 17A, 17B; frame bottom surfaces 15A, 15B; frame screw holes 19AU, 19AL, 19BU, 19BL for frame screws 18B, 18U; and frame recesses 126A, 126B for capturing PV laminates 20A, 20B. This view also shows how substantially constant spacing between PV modules 11 in an array 10 is automatically determined by the width of rotating portion 100, with minor material and assembly tolerance issues being allowed by

variable compression amounts on springs 106U, 106L. For example, manufacturing of a perfectly square PV module 11 is very difficult. Therefore it is common for PV modules to have widths and lengths that vary by up to 1/8". In prior art systems this variance is not accounted for. The springs 106U, 106L as shown here provide a degree of compliance that helps to mitigate the compounding of tolerance errors and therefore major problems with proper alignment during installation.

FIG. 4 depicts a perspective view of two adjacent PV modules 11A, 11B which are coupled together with two couplings 50a. Since slots 26A, 26B may run substantially the whole length of frames 12A, 12B, couplings 50a may be located at substantially any point along the length. Given the high strength connection provided, in practice one to three couplings per seam between two PV modules is typically adequate. At a corner 130 of each PV module 11 the flanges 108AU, 108AL, 108BU, 108BL are cut off thus allowing coupling 50a to easily slide from the seam between one set of PV modules 11 over to the seam between an adjacent pair of PV modules 11 when coupling 50a is in first position 91 as discussed above.

Referring now to FIGS. 5-6, FIG. 5 depicts a perspective view of a height adjustable bracket 132 which is suitable for connection to a PV module 11 of the first embodiment of the present invention, and FIG. 6 shows a cross-section cut through two adjacent PV modules 11A, 11B which are coupled together with a coupling 50a (not picture here for clarity, see FIG. 3). An L-shaped bracket 132 comprises a z-axis or vertical adjustment slot 140 and a y-axis adjustment slot 142 (coordinate system based on plane of mounting surface, see FIG. 7). A channel bolt 136 with bolt head 137, which is threaded into a channel nut 134, is utilized to attach bracket 132 to outside surface 16B of frame 12B. Channel nut 134 is shaped to fit inside slot 26B and to be captured behind flanges 108BU, 108BL. This embodiment contemplates a simple rectangular shape for channel nut 134 with nut 134 being inserted at corner 130 and slid into position. Threading bolt 136 into nut 134, sliding bracket 132 between bolt head 137 and frame outside surface 16B, and then tightening bolt 136 serves to pull nut 134 solidly against flanges 108BU, 108BL thereby rigidly securing bracket 132 to frame 12B. And since slot 26B runs substantially the whole length of frame 12B, bracket 132 can be attached to substantially any point along the length, which will be referred to as the x-axis direction. Therefore, slot 26B along with slot 140 and slot 142 allows for 3 dimensional adjustability of bracket 132, enabling greatly simplified installation via much easier lining up of brackets 132 with rafters (which typically run in the y-axis direction) and much easier leveling and aligning of PV modules within array 10. Lag screw 138 provides a means of directly securing bracket 132, and therefore array 10, to a mounting surface 144, such as a roof without any other support structure as is typical in prior art systems.

Please note that while FIG. 6 shows a connection of bracket 132 to right frame 12B, it can be connected to any outside surface 16, and furthermore it can be reversed so that lag screw 138 is positioned beneath the PV module 11 to which it is connected. In other embodiments nut 134 comprises a rectangular shape with two opposing rounded corners, similar to locking portion 104B, so that it can be inserted into slot 26B from any point along frame 12B and then twisted 90 degrees to tuck behind flanges 108BU, 108BL. In still other embodiments nut 134 is a standard hexagonal-shaped nut.

One alternate embodiment removes lower flanges 108AL, 108BL from slots 26A, 26B and the lower portions of locking portions 104A, 104B resulting in a one-sided locking action instead two as with the first embodiment.

First Embodiment—Basic Operation

Referring to FIGS. 7-8 and FIGS. 10-11, a PV array 10 according to the first embodiment of the present invention is shown installed on the roof of a building 146. FIG. 7 depicts a perspective view of building 146 with PV array 10 shown attached to a roof 144R which serves as a suitable mounting surface 144. Roof rafters 148 are just beneath the top surface of the roof and are shown as dashed lines. Brackets 132 can be seen in this view along the front of PV array 10. Brackets 132 are oriented such that lag screws 138 are hidden under PV modules. Brackets 132 can be seen attached to slots 26 on the outside surface 16 of the lowest row of three PV modules 11, one bracket 132 per PV module 11. Brackets 132 have been adjusted in their respective slots 26 in the x-axis direction such that each bracket 132 lines up with a rafter 148. Since lining up of brackets 132 with rafters 148 is only required with certain types of roofs and mounting surfaces, other embodiments provide brackets 132 which are not lined up with rafters, but rather attach directly to the mounting surface at any desired point. In still other embodiments, brackets 132 are adjusted in the x and y directions to line up with ground mounted structures, pier blocks, concrete posts, and specialized mounting hardware such as roof jacks, mounting posts, mounting jacks, tile brackets, specialized brackets, and stand-offs. Since the inventive system provides three dimensional adjustability, it can be connected to almost any suitable mounting surface.

FIG. 8 shows a side view of the same PV array 10 from FIG. 7 at a larger scale. This figure helps to clarify the fact that PV array 10 is connected to roof 144R without the use of strut or other supports. Brackets 132 connect frames 12 directly to roof 144R, and couplings 50a interlock PV modules 11 together. In contrast, FIG. 9 shows a typical prior art PV array 10PA without the benefit of an interlocking system as disclosed herein. PV modules 11PA are first linked together by struts 131PA. Struts 131PA are then attached to a mounting surface (not shown) via brackets 132PA. As can be seen here strut 131PA is a device which is at least as wide as two PV modules 11PA and is designed to support the opposing sides of at least two PV modules 11PA. A coupling, on the other hand, only joins PV modules together at the seam between the two modules and therefore is not wider than a single module. The fact that struts 131PA are designed to span between modules 11PA means that a lot of extra material is required. The additional expense and installation time required to utilize strut 131PA is a significant drawback to prior art systems.

FIG. 10 shows a perspective view of the same PV array 10 from FIG. 7 except that array 10 is being viewed from the back (exactly 180 degrees around from the FIG. 7 view) with building 146 removed to reveal the back side of PV array 10. In this view it is now evident that a row of three brackets 132 is located along every horizontal seam 150 between PV modules 11 and along the top 154 and bottom 156 edges of array 10. This method of relatively evenly distributing brackets 132 across array 10 is not possible with prior art strutless systems which utilize series couplings (see discussion below).

FIG. 11 shows a cross-section cut through PV array 10 (from FIG. 7) just above couplings 50a and looking perpendicular to array 10 thereby revealing the locations of

couplings **50a** and brackets **132** (roofing material not shown beneath array **10** for clarity). Couplings **50a** are shown interlocking all PV modules **11** in array **10** at all horizontal **150** and vertical **152** seams between PV modules **11**. In other embodiments couplings **50a** are only utilized on either horizontal seams **150** or vertical seams **152**. The arrangement of couplings as shown here creates a double structure or parallel interlock support system **160** for array **10** along both the x and y-axes as will be discussed below. Each frame **12** is referred to as a hybrid, strut-like frame because, unlike most prior art systems, it performs the following basic functions which are normally shared between a PV frame and a strut or similar structural support system: (a) holding and protecting the edges of PV laminate **20**; (b) interconnecting modules **11** together with a structural support system (in order to increase structural integrity and minimize the number of required connection points to mounting surface **144**); and (c) providing a means for attaching array **10** to mounting surface **144** via foot-type or bracket members.

First Embodiment—Series and Parallel Coupling Theory

FIG. **12** provides a simplified top view of two adjacent rectangular frames A and B. Lines C_1 , C_2 , C_3 , and C_4 represent places along the seam between the two frames A and B where couplings can theoretically be placed. Couplings which connect at lines C_1 and C_2 are referred to as parallel couplings since a union of frames A and B at these points results in frames A and B being interlocked in parallel. It follows then that any point along the seam between A and B is theoretically capable of receiving a parallel coupling. However, the corner points K_1 and K_2 are special cases since prior art slots in the outside surfaces of frames do not extend all the way to the corner on both sides of a pair of orthogonal frame members. This problem arises from the nature of the aluminum extrusion process (which is how most PV frames are manufactured) and prevents the sliding of parallel couplings all the way to the end on at least two sides of a rectangular PV module. The corners are also a special case for a second reason. The corners K_1 and K_2 are the only places around the perimeter where a coupling can be inserted into the outside surface of a first frame member B_4 and continue through into a second frame member B_3 which is around the corner from the point of insertion. Thus, lines C_3 and C_4 are shown extending from parallel frame members A_2 , B_4 into the orthogonal frame members B_1 , B_3 and A_1 , A_3 . Since the ability to run a coupling into an orthogonal frame member clearly enhances the structural properties (z-axis loads can be distributed over a larger area), prior art couplings fall into two basic categories: parallel couplings which are optimized to connect to the side of a frame member substantially anywhere along the whole length of the member and series couplings which are optimized for the special case of connecting to the ends of frame members at the corner points K_1 , K_2 . Series couplings are so named because they link two frame members, such as A_3 and B_3 , end to end.

In order to understand the operation of PV array **10** of the first embodiment, it is important to first understand how the forces that are presented to PV array **10** are distributed across it. Forces can act over the entire surface, such as a wind pressure, or forces can be highly localized, such as someone stepping on it. In either case, these forces must find their way to the roof **144R** or mounting surface **144** via brackets **132** that mount the PV system, and these brackets **132** may be some distance away from the point or area of application of

the force. In many cases the force must pass across PV modules and the transitions between them in order to make it to mounting surface **144**. A coupling device for interlocking frame members **13** provides an opportunity to further support frame members **13** by locking it to adjacent frame members **13**. For an individual PV module **11** each frame member **13** acts as a separate structural entity which is supported by PV laminate **20** and connected to orthogonal frame members at the corner joints. Even in a hypothetical case of a framed PV laminate which comprises a frame constructed out of a single piece of material (no such example exists to our knowledge), each side of the frame is still a separate structural entity since the sides are mostly separated by the laminate and only connected by a small portion in the corners. Thus, it is important to discuss which frame member and where on the frame member a particular coupling is connected if one wants to understand the structural properties of the coupling. Assuming that PV module **11** comprises substantially straight frame members **13**, then the possible shapes (in a top view) for flat-plate PV module **11** are a triangle, rectangle, pentagon, hexagon, etc. All such shapes are suitable for use with the present invention.

FIGS. **13-14** show generic PV arrays **10P** and **10S**, comprising four PV modules **11A**, **11B**, **11C**, **11D** with adjacent frame members **13A1**, **13B1**; **13A2**, **13C2**; **13B2**, **13D2**; **13C1**, **13D1** respectively. These two figures demonstrate the two basic types of couplings which are possible in a rectangular array: parallel couplings **50** and series couplings **62**. When straight-sided PV modules **11A**, **11B**, **11C**, **11D** are assembled to form substantially rectangular PV arrays **10P** and **10S**, the result is a plurality of frame members **13** which are immediately adjacent to each other (within arrays **10P**, **10S**) and a plurality of frame members **13** around the perimeter of arrays **10P**, **10S**. FIG. **13** shows parallel couplings **50** that each connect two adjacent and substantially parallel frame members **13** side to side. FIG. **14** shows series couplings **62** that each connect two substantially collinear frame members **13** end to end.

As shown in FIG. **13**, parallel couplings **50** allow a force F_1 applied to PV module **11B** to be distributed between the PV modules immediately adjacent to it, **11A** and **11D**, along paths P_1 , P_2 , P_3 , as well as out to the more remote PV module **11C** along paths P_4 and P_5 . This distribution of forces is enabled since parallel couplings **50** allow both the connection of frame members **13** end to end and side to side. For example, frame members **13B1** and **13A1** are interlocked in addition to the orthogonal pair of frame members **13B2** and **13D2**. This connection of orthogonal pairs of frame members **13** enables the connection of each row of PV modules **11A**, **11C**, to the adjacent row **11B**, **11D** and allows force F_1 to be distributed across all the PV modules in array **10P**, thus strengthening the entire frame structure supporting PV laminates **20**. However, series couplings **62**, as shown in FIG. **14**, will only allow forces to be distributed down the rows **11A**, **11C** and **11B**, **11D** which are attached in this way. The same force F_1 presented to module **11B** in this case can only take paths P_{10} and P_{11} , thus preventing the distribution of loads to PV modules **11A**, **11C**.

While series couplings **62**, as are known in the prior art, are clearly less advantageous than parallel couplings, some embodiments of the present invention, as will be discussed below, provide a means for adding a series coupling portion to a parallel coupling thereby creating a series-parallel coupling. There are distinct advantages to such a hybrid coupling since in theory a series coupling may provide more opportunity for enhancing the z-axis strength of frame **12** (though such potential is not realized in prior art couplings).

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Parallel interlock support system **160** operates as follows. The specialized slot **26** allows couplings **50a** to securely connect the sides of each immediately adjacent and parallel pair of frame members **13**. It is common for installation technicians to step on a PV laminate **20** during installation. This action provides a localized load such as would generate force F_1 . In prior art strutless systems, force F_1 is translated to the frames which are nearest to the point of loading, and each frame member **13** is acting mostly independently since there are no securely connected additional supporting members nearby. In the first embodiment of the present invention, however, force F_1 presented to the top of PV laminate **20** is shared by frame **12** which surrounds PV laminate **20** as well as the four frame members **13** which are coupled to the loaded PV laminate **20**. Thus, it can be seen that a support grid is created by the simple and rapid connection of couplings **50a** to adjacent frames **12**. This grid is evenly distributed in the x and y directions throughout array **20**, and the doubled support members run beneath the edges of each PV laminate **20**. The result is a PV array **10** which can be mounted to a roof or other mounting surface **144** without the need for costly and heavy strut (or other structural members). Furthermore, the increased spanning capabilities provided by the parallel interlock support structure **160** significantly reduce the number of connection points (and therefore brackets **132**) for a given size array **10** on a given mounting surface **144** as compared to prior art strutless systems.

FIG. **15** shows a prior art strutless PV array **210PA** with PV modules **211PA**, brackets **232PA**, and series couplings **250PA**. As discussed above, series couplings must be connected at the corners and therefore they cannot be used to connect two adjacent rows together. Thus, brackets between rows must be doubled up (as shown) or specialized (and difficult to install) double brackets must be utilized. And, as mentioned above, the total number of brackets **232PA** is also increased relative to the inventive device of the first embodiment because spans between brackets **232A** cannot be as long.

First Embodiment—Coupling Modes

The unique structure of the framing and coupling systems of the first embodiment enables three distinct modes of operation: positioning mode, locked mode, and sliding mode. In the first embodiment these different modes may be easily accessed via rotation of coupling **50a** into one of the three discrete positions **91**, **92**, **93** as discussed above. Other embodiments access these modes via different means as will be discussed below.

Positioning mode is primarily utilized during installation and removal of PV modules **11** in PV array **10**. Positioning mode secures coupling **50a** to one PV module **11** of a pair of PV modules **11** to be interlocked. Since the positioning of PV modules can be difficult, particularly on sloped roofs, positioning mode insures that coupling **50a** will stay in position as the two modules are guided together. Thus, in positioning mode coupling **50a** is either firmly secured or loosely attached to one PV module **11**.

Locked mode is the mode that all couplings are left in once array **10** is fully installed. Locked mode securely interlocks two adjacent PV modules **11** together thereby forming a parallel interlock support system **160** as discussed above. In locked mode coupling **50a** is firmly secured to two adjacent PV modules. This mode also automatically grounds the two interlocked modules **11** to each other and forces them into proper alignment and spacing. The automatic

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grounding feature of the first embodiment of the present invention provides a substantial improvement over prior art systems because PV modules are electrically grounded to each other both within rows of modules **11** and between rows. Thus a complete x-y grounding matrix results so that only one ground wire needs to be run from PV array **10** to the grounding equipment for the site.

Sliding mode is primarily used during installation and removal of PV modules **11** in array **10**. Sliding mode partially decouples two interlocked PV modules so that coupling **50a** may be repositioned or slid all the way down slot **26** and over into slots **26** for an adjacent PV module pair in array **10**. This allows removal of an individual PV module **11** that is surrounded by adjacent PV modules **11** installed on all sides. Thus in sliding mode coupling **50a** is loosely attached to two adjacent PV modules. Prior art systems do not teach or imply a PV array coupling and framing system capable of achieving all three of these coupling modes (positioning, sliding, and locked).

First Embodiment—Coupling Process

FIGS. **16**, **19**, and **22** depict a perspective view of coupling **50a** in each of its three discrete positions **91**, **92**, **93** respectively as it is utilized to interlock two adjacent frames **12A**, **12B** together (only a portion of frames **12A**, **12B** are shown so that locking portions **104A**, **104B** are revealed). Please note that since coupling **50a** may be installed in either frame first, FIGS. **16**, **19**, and **22** show frames **12A**, and **12B** in opposite positions than in FIG. **3**. FIGS. **17-18** show front and back side views respectively of coupling **50a** in first position **91**. FIGS. **20-21** show front and back side views respectively of coupling **50a** in second position **92**. FIGS. **23-24** show front and back side views respectively of coupling **50a** in third position **93**. The following description also references FIGS. **2-3** since some parts are easier to see in closer views.

The process of interlocking two adjacent frames **12A**, **12B** is as follows. First, coupling **50a** is oriented in first position **91**, which aligns the length of locking portion **104A** with the length of slot **26A**, then inserted at substantially any point along frame **12A** into slot **26A**. While inserting, the direction of travel is substantially parallel with the plane of laminate **20A** and substantially perpendicular to the length of slot **26A**. Coupling **50a** is inserted until locking portion **104A** hits the back of slot **26A** or rotating portion **100** contacts outside surface **16A** of frame **12A**. FIG. **16** shows coupling **50a** in first position **91** and fully inserted. For convenience, we contemplate alignment of rotating portion flat faces **116** at 45 degrees to the plane of laminate **20** when in first position **91**: this way the corner point of rotating portion **100** is pointing straight up and is therefore easy to align by eye. Of course other orientations for flat faces **116** will work just as well. One skilled in the art will recognize that springs **106U**, **106L** are oriented such that they are not touching frames **12** in first position **91** (since they line up with opening **27A**, **27B** of slot **26A**, **26B**). Therefore, a return to first position **91**, even after the complete array **10** has been installed, will enable sliding mode since it is not locked onto either frame and since springs **106U**, **106L** are not compressed.

The second step is to rotate coupling **50a** into second position **92** in order to enable positioning mode as is depicted in FIGS. **19-21**. Though lighter duty springs may be used, we contemplate the use of relatively stiff springs for springs **106U**, **106L** since movement of the modules **11** in array **10** may be undesirable once the installation is com-

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plete. Springs with a full deflection rating of 100 to 500 pounds may work well, but other spring rates are also suitable. Thus, in order to move coupling 50a from first position 91 to second position 92, a wrench is applied to rotating portion 100 to rotate it approximately 45 degrees clockwise. In this position locking portion 104A is locked onto frame 12A and springs 106U, 106L are partially compressed. Please note that during the first part of the 45 degree rotation from first position 91 to second position 92, tapered surfaces 105AU, 105AL engage with flanges 108AU, 108AL to pull the locking portion further into the slot. By guiding locking portion 104A into place, tapered surfaces 105AU, 105AL also enable an increased range of acceptance angles for initial alignment of locking portion 104A and therefore increase the flexibility and ease of use of coupling 50a since it doesn't have to be "dead on" in order to rotate. As coupling 50a is being rotated from first 91 to second 92 position, teeth 112 AU, 112AL begin to bite into flanges 108AU, 108AL when the end of tapered surfaces 105AU, 105AL is reached. From this point on through the rest of the full 90 degree throw, the surfaces of locking portion 104A which are in contact with flanges 108AU, 108AL remain relatively parallel with flanges 108AU, 108AL. Therefore, the force applied by springs 106U, 106L effectively squeezes coupling 50a about flanges 108AU, 108AL and it is held in a stable position if the wrench is removed from rotating portion 100. Thus, second position 92, as shown in FIG. 19, is a stable discrete position with coupling 50a attached only to frame 12A. The second frame 12B can now be moved into or out of position without knocking coupling 50a out of position. Unlike some prior art systems which require both PV modules 11A, 11B to be in place and aligned before a coupling can be connected, the inventive device of the first embodiment allows free positioning of modules with coupling 50a connected to one of them in positioning mode. For example, in some cases it may be advantageous to insert couplings into some PV modules 11 on the ground before taking them up to a roof to be mounted. In other cases couplings 50a may be locked onto PV modules 11 at the factory prior to shipping. Also, when interlocking a free PV module to an already mounted PV module, coupling 50a may be attached to either the free PV module or the already mounted PV module. Positioning mode is enabled since locking portion 104B is shaped such that it only begins to lock itself onto frame 12B when coupling 50a is being rotated from second position 92 to third position 93.

FIGS. 22-24 depict coupling 50a in third position 93, securely attached to frames 12A, 12B in locked mode. The process of rotating from second position 92 to third position 93 is basically the same as that from first 91 to second 92. A wrench is used to rotate rotating portion 100. Tapered surfaces 105BU, 105BL guide locking portion 104B into slot 26B and teeth 112BU, 112BL begin to bite into flanges 108BU, 108BL when the end of tapered surfaces 105BU, 105BL is reached. Arrival at third position 93 is signaled by locking portion stops 120AU, 120AL contacting upper 122AU and lower 122AL inside surfaces of slot 26A respectively and 120BU, 120BL contacting upper 122BU and lower 122BL inside surfaces of slot 26B respectively. Locking portion stops 120AU, 120AL, 120BU, 120BL provide a solid, hard stop which prevents rotation of the wrench any further, therefore significantly simplifying the installation procedure and increasing the quality thereof by eliminating the possibility of over or under-torqued bolts.

The above discussion of the coupling process clearly shows how a rotation of coupling 50a from first position 91 to third position 93 causes locking portion 104A to bear

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against inside surfaces 109AU, 109AL of slot 26A and rotating portion 100 via springs 106U, 106L to bear against an opposing frame surface, outside surface 16A. Since springs 106U, 106L act to transfer forces from rotating portion 100 to frames 12A, 12B, they are also referred to as force transfer portions. Likewise locking portion 104B bears against inside surfaces 109BU, 109BL of slot 26B and rotating portion 100 via springs 106U, 106L bears against an opposing frame surface, outside surface 16B. Thus it is clear that coupling 50a securely interlocks PV modules 11A and 11B together by bearing against opposing surfaces on each frame 12A, 12B upon rotation of rotating portion 100.

Please note that this method of interlocking is quite different from most prior art systems which interlock adjacent PV modules by means of a coupling that bears against the frame and a strut, a mounting rail, a bracket, or other structural member which is sandwiched between opposite ends of the coupling. This basic structural difference enables the forming and mounting of PV arrays 10 without requiring the use of separate structural support members (such as strut, mounting rails, and the like) which attach directly to and span between multiple PV modules in a formed PV array 10.

First Embodiment—Installation Methods

Referring to FIGS. 7-8 and FIGS. 10-11, the basic steps involved in the forming and mounting of PV array 10 according to the second embodiment of the present invention may be as follows:

Step 1: Secure a first PV module 11 to roof 144R with at least one bracket 132.

Step 2: Interlock a second PV module 11 to the first PV module 11 with at least one parallel coupling 50a which interlocks the sides of two adjacent frame members 13 together in parallel.

Step 3: Attach second PV module 11 to roof 144R with at least one bracket 132.

Step 4: Repeat steps 2 and 3 for all remaining PV modules 11 in PV array 10, successively interlocking each new PV module 11 to the side of a mounted PV module 11 and attaching at least one bracket 132 to each module.

The details of Step 2 above may be as follows: insert coupling 50a into slot 26 of the mounted PV module 11, rotate rotating portion 100 to second position 92 with a wrench thereby enabling positioning mode, mate second PV module 11 with coupling 50a, rotate coupling 50a to third position 93 thereby enabling locked mode. The wrench is operated from above by sliding wrench between the two modules 11 (which may be as close as approximately 1/4" apart). Alternately coupling 50a may be placed on the free module 11 for positioning mode instead of the mounted module 11.

The details of Step 3 may be as follows: install bracket flashing or mounting plate, loosely install bracket 132 on mounting plate, attach bracket 132 to PV module 11 at any point along the side where it lines up with required bracket placement, secure bracket 132 to mounting plate. Since there are many types of mounting surfaces, there, of course numerous ways that brackets 132 can be installed. Thus, the inventive system of the first embodiment provides slot 26 and height adjustable bracket 132 in order to provide maximum flexibility in adapting to almost any mounting situation.

Parallel couplings 50a may be used at substantially any point in any horizontal 150 or vertical 152 seam between adjacent PV modules. Each seam 150, 152 may include one, multiple, or no couplings 50a depending on the installation

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requirements. Substantially all brackets **132** may be attached by sliding channel nuts **134** into slots **26** from the end, aligning with bracket **132**, and screwing bolt **136** into channel nut **134** to capture bracket **132**.

Final tightening of each coupling **50a** and bracket **132** connection is flexible and does not necessarily coincide with initial placement in array **10** of that module **11**. This flexibility allows PV modules **11** to be temporarily positioned in the array while others are positioned or while wiring or other installation issues are handled. Since all couplings **50a** are capable of being tightened from the top, PV modules **11** can be moved into locked mode at any time. One skilled in the art will recognize that the 2-axis nature of the couplings in the embodiment under discussion means that PV modules **11** can be installed in any order and in substantially any shape for PV array **10** as long as each new PV module **11** is interlocked to a mounted PV module **11**, and all new modules **11** are added to a mounted module which has a portion of a frame member **13** free (not already interlocked to another PV module). It is possible, for example, to mount PV modules in a generally rectangular shape, but then leave out modules **11** in the middle to avoid vents or other obstructions. In another example, each row of PV modules **11** may be displaced by a specific amount for architectural reasons or to match a roof line.

If a module **11** needs to be removed from the middle of a formed array for servicing, the required steps may be as follows. First, move all couplings **50a** which are connected to it back into first position **91** with a wrench from above thereby enabling sliding mode for each. Then slide all loosened couplings **50a** over to neighboring modules **11**. In some cases a bracket **132** may prevent sliding in one direction but not both. Brackets **132** are typically installed with one per module, so there is normally at least one direction to slide. If two brackets **132** are required, then couplings **50a** are not used in between the two brackets **132**. Next, loosen bolts **136** which connect brackets **132** to frames **12** on the effected module **11** and lift it straight up and out of array **10** (disconnecting wires before moving it too far). In this way an individual PV module **11** that is installed in the middle of array **10** may be removed without requiring the removal of the surrounding modules **11**, thereby substantially saving time during troubleshooting and maintenance as compared to prior art systems.

In another embodiment PV modules **11** comprise non-rectangular shapes such as triangular or hexagonal and the coupling system works in the same manner as described above. In another embodiment PV modules **11** are small enough to not require one bracket **132** per module. In this embodiment multiple modules are interlocked together and then one of the group is attached to roof **144R** with bracket **132**. In yet another embodiment PV array **10** is mounted to a ground-mounted rack system instead of roof **144R** with no change in the basic installation method outlined above except that brackets **132** are attached to the rack instead of roof **144R**. In still another embodiment groups of standardized PV modules **11** are interlocked together via couplings **50a** on the ground and then hoisted to a roof where brackets **132** are used to secure them in place.

First Embodiment—Advantages

The first embodiment of the present invention provides numerous advantages over prior art systems. Inventive features of the present apparatus include, but are not limited to the following:

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Parallel coupling action—parallel coupling is attachable to substantially the whole length of all four sides of a PV module and securely locks the outside surfaces of parallel frame members together in a side to side arrangement, thereby increasing the structural performance of the PV array.

Three mode design—Parallel coupling is shiftable with a wrench into three modes of operation: positioning mode, sliding mode, and locked mode. A positive stop is provided when locked mode is reached.

Locking portion—Parallel coupling provides two specially shaped locking portions which are insertable into slots on the outside surfaces of adjacent frame members. Locking portions enable discrete positions of device and provide a positive stop for locked position.

Dual bearing action—Parallel coupling interlocks adjacent frame members together by bearing against opposing surfaces on each frame upon rotation of a rotating portion. Locking portion bears against an inside surface of the slot and the coupling bears against an opposing surface.

Twist-lock action—Parallel coupling provides a rotating portion which shifts from an unlocked position to a locked position in approximately 90 degrees of rotation.

Top accessible—Parallel coupling is accessible from the top even after PV array has been formed. Coupling can be rotated with a wrench from above to shift from locked mode to sliding mode so that coupling can be slid into the slots of neighboring PV modules. In this way a single PV module can be removed from the middle of a formed PV array.

One-piece—Parallel coupling is deployable in the field as a one-piece unit.

Automatic alignment—Parallel coupling forces interlocked PV modules into alignment along both the x and y axes of PV array. Spacing between modules and height of modules is automatically set upon rotation into locked mode.

Automatic grounding—Rotation of parallel coupling into locked mode causes integral teeth to bite into frame members thereby enabling reliable x-y matrix grounding for the whole PV array. Only one wire is required to ground the whole PV array and the ground connection is uncompromised by the removal of a PV module from the PV array.

Tolerance compensation—Parallel coupling minimizes alignment problems due to variable tolerances within PV array via an integral spring. Spring also resists unlocking of mechanism over time and helps to minimize grounding problems by maintaining a known amount of force on ground connection.

Multifunction frame—A frame is provided which supports PV laminates and eliminates the need for a strut system which links modules together in a PV array. Each frame member comprises a specially shaped slot which enables the connection of parallel couplings and mounting brackets to substantially the whole length of all four sides of a PV module. Furthermore each slot comprises flanges which enable high-strength interlocking and the connection of snap-on options such as cosmetic flashings and debris screens.

The above features provide many useful benefits including, but not limited to: strutless design, minimal attachment points, accessible yet hidden wiring, flexible mounting options, three dimensional adjustability, rapid formation of PV array, better load distribution, better airflow, more flexible wiring options, low part count, improved aesthetics due to lower profile and better alignment, and increased flexibility for orientation (landscape or portrait o.k.).

When removing the strut from a PV mounting system, significant structural challenges are revealed. We will now discuss in more detail the structural advantages of the first embodiment relative to prior art strutless systems.

First, coupling **50a** maximizes structural integrity relative to size by operating on frame **12** in a direction substantially perpendicular to outside surface **16** (instead of parallel to it). This fact enables the cost-effective creation of flanges **108AU**, **108AL**, **108BU**, **108BL** in frame **12** extrusion which provide a thick and very strong surface that coupling **50a** utilizes as a wall for holding the ends of locking portions **104A**, **104B**. This arrangement results in a very high pull-out strength as compared to the press-fit resistance provided by prior art systems. The flanges **108AU**, **108AL**, **108BU**, **108BL** are described as cost-effective since they run longitudinally in the same direction that an extrusion process would run in order to extrude frame members **13** in a typical manufacturing process. Creation of equivalent flanges running at 90 degrees to flanges **108AU**, **108AL**, **108BU**, **108BL** as required by prior art systems requires additional machining operations.

Second, the major part of the coupling can be located in the gap between modules instead of inside the frame member, thereby reducing the required size for the frame.

Third, attaching coupling **50a** to outside surface **16** of frame **12** with locking portions that engage positively inside both the top and bottom frame member flanges **108AU** and **108AL**, allows coupling **50a** to resist forces that would separate the opposing frame outside surfaces **16**, especially in comparison to prior art systems. Furthermore, because it is these separating forces that are the primary forces that we need to overcome with such a coupling, and it intrinsically does this in an effective manner, it can be designed smaller than prior art solutions, and will therefore involve lower material costs.

Fourth, teeth **112AU**, **112AL**, **112BU**, **112BL** enhance the longitudinal holding strength of coupling **50a** since they are circular to facilitate biting into frame **12** as rotating portion **100** is rotated to lock coupling **50a**. These teeth therefore resist being dragged along the longitudinal axis.

In addition to the structural advantages discussed above, the grounding system provided by the first embodiment of the present invention also has unique benefits. The system is more reliable than the prior art since the amount of force supplied to the grounding means is dependant on the stiffness of springs **106U**, **106L**. Once the correct spring size is determined, all couplings will supply a consistent amount of force to the ground connection and this force will not be dependant on how hard a technician tightens the coupling.

It follows from the above discussion that the first embodiment of the present invention provides significant advantages over prior art systems. Other objects and advantages of the present invention will also be discussed.

Second Embodiment—Structure

FIGS. **25-31** depict a second embodiment of the present invention. This embodiment is similar to the first embodiment described above except that it includes minor changes to the framing and coupling systems in order to lower manufacturing costs and simplify installation.

FIGS. **25-26** present a cross sectional view of two interlocked modules **211A**, **211B** and a perspective view of four interlocked PV modules **211A**, **211B**, **211C**, **211D** respectively. Slot **26A**, **26B** is removed from two opposing frame members **13** yielding a hybrid, strut-like frame **212** with two un-slotted frame members **913** and two slotted frame mem-

bers **213**. Un-slotted frame members **913** may be smaller and lighter weight than slotted frame members **213**. In another embodiment un-slotted frame members **913** are made from a lightweight plastic material and are primarily used to protect laminate **20** edges (instead of providing structural support). In another embodiment frame members **913** are not used at all.

Frames **212A**, **212B**, **212C**, **212D** each comprise an outside surface **216A**, **216B**, **216C**, **216D**; an inside surface **217A**, **217B**, **217C**, **217D**; a top surface **214A**, **214B**, **214C**, **214D**; and a bottom surface **215A**, **215B**, **215C**, **215D** (not all surfaces viewable in these drawings). Four interlocked PV modules **211A**, **211B**, **211C**, **211D** are oriented such that slots **226A**, **226B** with openings **227A**, **227B** parallel each other and slots **226C**, **226D** with openings **227C**, **227D** parallel each other. The two modules **211A**, **211B** comprise slot inside surfaces **209AU**, **209AL**, **209BU**, **209BL** (modules **211B**, **211C** comprising like surfaces which are not labeled). Thus, all slotted frame members **213**, except those around the perimeter of array **10**, may be located immediately adjacent to other slotted frame members **213**, and all un-slotted frame members **913**, except those around the perimeter of array **10**, may be located immediately adjacent to other un-slotted frames sides **913**. The designation PV module **211** refers to any PV module in array **10** and the designation **212** refers to any PV module **211** frame in array **10**. Likewise a slot **226** refers to any slot **226A**, **226B**, **226C**, **226D** within array **10**.

In order to maintain structural linking in both the x and y directions, as is shown in the first embodiment described above, the second embodiment of the present invention replaces coupling **50a** with a parallel coupling **50b** in some locations. In other locations a parallel coupling **50j** is utilized in place of coupling **50a**. In locations where two frame members **13** have been changed to un-slotted frame members **913** there are no couplings since there is no slot **26** for coupling connection. Parallel coupling **50b** is also referred to as a double coupling or series-parallel coupling **50b** because it further comprises a series coupling portion **162** which is utilized to provide a series coupling connection to a second pair of adjacent PV modules. Thus parallel coupling **50b** interlocks four PV modules **211A**, **211B**, **211C**, **211D** instead of two as is typical in prior art systems. A more detailed description of the layout of couplings **50b** and **50j** is provided below. All couplings **50j** and **50b** are shown here in horizontal seams **150**, but other embodiments provide all couplings **50j** and **50b** in vertical seams **152**. In still other embodiments frame members **13** are substantially similar on all four sides and therefore couplings **50j** and **50b** are located in both the horizontal **150** and vertical seams **152**.

FIG. **27** depicts a perspective view of a generally rectangular-shaped parallel coupling **50b**. Coupling **50b** comprises two parallel coupling portions **50bb** and a series coupling portion **162**. Parallel coupling portions **50bb** are similar to couplings **50j** (described below) except that they may be shaped slightly differently in order to work well with series coupling portion **162**. For example, in one embodiment parallel coupling portions **50bb** are similar to couplings **50j** except that they further comprise retainer portions which enable them to be movably secured to series coupling portion **162**, thereby allowing coupling **50b** to be deployed as a one-piece unit in the field. In the present embodiment under discussion coupling portions **50bb** are the same as couplings **50j** thus allowing coupling **50b** to be a three piece unit comprising two parallel coupling portions **50bb** and one series coupling portion **162**. In another embodiment more than two coupling portions **50bb** are utilized for additional

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strength. In still another embodiment series coupling portion **162** comprises retainer portions which enable parallel coupling portions **50bb** to be movably secured to series coupling portion **162**, thereby resulting in a one-piece coupling **50b**.

Referring to FIGS. **25-27**, series coupling portion **162** comprises a first side **164** adapted to mate with outside surfaces **216A**, **216C** of the four interlocked PV modules **211A**, **211B**, **211C**, **211D**. First side **164** comprises three male protrusions which mate with frames **212A**, **212C** to increase the strength of frames **212A**, **212C** at the point of coupling. Male protrusion **165** is adapted for insertion into auxiliary slots **224A**, **224C** in frames **212A**, **212C** and may be tapered slightly to insure a snug fit is maintained despite tolerance issues. Male protrusion **166** is adapted for insertion into slots **226A**, **226C** in frames **212A**, **212C** and comprises teeth **168U**, **168L** which bite into frames **212A**, **212C** to insure solid electrical ground contact and to enhance the structural connection between PV modules **211A**, **211C**. Male protrusion **166** may be tapered. Male protrusion **167** is adapted to slide just beneath frames **212A**, **212C** and may be tapered as well. In other embodiments male protrusions **165**, **166**, **167** may not be tapered. Series coupling portion **162** further comprises at least two slots or holes **170A**, **170B** which allow insertion of parallel coupling portions **50bb** as discussed below and a second side **172** which faces away from PV modules **211A**, **211C** when series coupling portion **162** is installed. In another embodiment teeth **168U**, **168L** are replaced by teeth on a different surface of series coupling portion **162** or a different portion of coupling **50b**. In other embodiments series coupling portion **162** has various numbers of male protrusions. In still another embodiment there are no male protrusions on series coupling portion **162**. We contemplate making series coupling portion **162** in a length of approximately 3-12" and out of a rigid material such as aluminum or steel, though other materials and lengths are possible.

FIG. **28** shows a perspective view of parallel coupling **50j** which comprises all of the same portions as coupling **50a** except the following. First, shaft portion **102A**, designated here as **232A**, has been extended by approximately the width of bracket **132**. Second, rotating portion **100** has been replaced by rotating portion **200** comprising four springs **236A**, **236B**, **236C**, **236D**, (not all viewable here), two for each side of coupling **50j** oriented approximately 180 degrees apart. And third, spring bores **110U**, **110L** have been replaced by spring bores **240A**, **240B**, **240C**, **240D** to correspond with new springs **236A**, **236B**, **236C**, **236D**. Coupling **50j** further comprises locking portions **204A**, **204B** which function the same as locking portions **104A**, **104B**. All remaining portions of coupling **50j** are the same as coupling **50a** and are thus not specifically designated here. Parallel coupling portion **50bb** in this second embodiment is the same as coupling **50j** and thus also references the same designations.

FIG. **29** shows a perspective view of height adjustable bracket **132** and parallel coupling **50j**. Another advantage of the second embodiment of the present invention is that extended shaft portion **232A** allows coupling **50j** to perform a dual function of interlocking adjacent PV modules together as discussed above while also attaching bracket **132** to PV module **11**. This feature substantially reduces installation time when compared to prior art systems that require the tightening of separate fasteners for couplings and brackets. One skilled in the art will also recognize that vertical adjustment slot **140** in bracket **132** is approximately perpendicular to slot **26A**, **26B**, and that springs **236A**, **236B**, **236C**, **236D** are oriented so that in first position **91** all four

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springs are free and uncompressed in the same way as coupling **50a**. Many other spring variations are possible within the scope of the present invention.

FIG. **30** provides a cross-section showing two adjacent PV modules **212A**, **212B** which are interconnected with coupling **50j**. Coupling **50j** is shown in first position **91** as discussed above. When rotated approximately 90 degrees, coupling **50j** interlocks frames **212A** and **212B** together and simultaneously compresses bracket **132** against frame **212A**. Thus, channel nut **134** and channel bolt **136** are no longer needed.

Second Embodiment—Operation

FIG. **31** is the same as FIG. **11** except that PV array **10** utilizes the framing and coupling system of the second embodiment. Brackets **132** are shown in the same locations except now they are connected to frames **212A**, **212B**, **212C**, **212D** via couplings **50j**, thereby reducing total part count and installation time required for PV array **10**. Series-parallel couplings **50b** bridge the corner points where the four corners of PV modules **211A**, **211B**, **211C**, **211D** meet. For example, a coupling **50b** is shown bridging a corner point **295** where four PV modules **211A**, **211B**, **211C**, **211D** meet. Parallel coupling portions **50bb** interlock modules **211A**, **211B** and **211C**, **211D** while series coupling portion **162** interlocks modules **211B**, **211D** and **211A**, **211C**. Please note that a second series coupling portion between **211A**, **211C** is possible but not required since parallel coupling portions **50bb** lock frame **212A** to frame **212B** and frame **212C** to frame **212D** along with series coupling portion **162**.

Thus, the two axis parallel interlock support system **160** from the first embodiment is replaced by a single axis parallel interlock support system **260** which may run along the x-axis or y-axis. As shown in FIG. **31**, parallel coupling portions **50bb** and parallel couplings **50j** lock adjacent frame members **213** side to side in parallel which creates vertical rows of paired frame members **213** along the y-axis. Series coupling portions **162** interlock frame members **213** longitudinally along the x-axis, thereby connecting the vertical rows and increasing the overall strength of the system. Series coupling portion **162** is located between rotating portion **100** and outside surface of frames **216**. And since parallel coupling portion **50bb** is rotatable relative to series coupling portion **162**, a rotation of rotating portion **100** firmly compresses series coupling portion **162** into frames **212A**, **212C**. This action serves to substantially increase the strength of frames **212A**, **212C** relative to a z-axis load (such as wind) in the region of coupling **50b** since z-axis loads are distributed longitudinally down frames **212A**, **212C**. While some prior art couplings do also provide increased z-axis strength due this same effect, series coupling portion **162** may be substantially stronger for the following reasons: (a) since series coupling portion **162** is not fully contained within a slot or internal cavity of frames **212A**, **212C**, it is able to be much taller in the z-direction thereby increasing strength; (b) coupling portion **162** is secured to frames **212A**, **212C** by a compressive force about a portion of frames **212A**, **212C** which increases strength instead of a tensile force which tends to deform the frame and decrease strength; (c) coupling portion **162** comprises upper **165** and lower **167** male protrusions which tend to prevent deformation of frames **212A**, **212C** under load since they prevent widening of opening **227A** as seen in FIG. **25**; and (d) coupling portion **162** has no fixed center point and therefore may be slid in slots **226A**, **226C** to match up with high load areas.

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Accordingly, a rotation of parallel coupling portion **50bb** from first position **91** to third position **93** causes locking portion **204A** to bear against inside surfaces **209AU**, **209AL** of slot **226A** and rotating portion **200** via springs **236A**, **236C** to bear against series coupling portion **162** which in turn bears against an opposing frame surface, outside surface **216A**. In this case the bearing action of rotating portion **200** is transferred through springs **236A**, **236C** and series coupling portion **162** to frame **212A**. Therefore springs **236A**, **236C** and series coupling portion **162** are also referred to as force transfer portions. Since there is no series coupling portion **162** between rotating portion **200** and frame **212B**, this portion of the coupling process proceeds the same as discussed above for module **12B**. That is, locking portion **204B** bears against inside surfaces **209BU**, **209BL** of slot **226B** and rotating portion **100** via springs **236B**, **236D** bears against an opposing frame surface, outside surface **216B**. Thus, PV frames **212A** and **212B** are locked to coupling **50b** via rotation of rotating portion **200** from first position **91** to third position **93**. The other half of coupling **50b** operates in the same way to lock frames **212C** and **212D** to coupling **50b**. Thus it is clear that coupling **50b** securely interlocks PV modules **211A**, **211B**, **211C**, and **211D** together by bearing against opposing surfaces on each frame **212A**, **212B**, **212C**, **212D** upon rotation of rotating portions **200**. In other embodiments devices which are removable from a mounted PV module **211** along with coupling **50b**, such as washers, pressure distribution plates, and springs, are placed between coupling **50b** and frame **212**. In these cases such devices are sometimes referred to as force transfer portions and are considered to be part of coupling **50b** in the same way that series coupling portion is so incorporated. On the other hand, brackets and struts which span between PV modules **211** and/or are attached to a mounting surface are not considered to be a part of coupling **50b** since they are not removable with coupling **50b**.

As shown in FIG. 30, the second embodiment of the present invention provides a means for reducing parts and labor costs by combining the function of attaching bracket **132** with the function of interlocking two adjacent PV modules **211A**, **211B**. Thus, the installation of PV array now has one less step. To our knowledge there are no prior art systems which teach a combined functionality coupling which can both couple the sides of two adjacent PV modules together in parallel and simultaneously secure a height adjustable bracket to the side of frame **212A**.

The basic steps involved in the forming and mounting of PV array **10** according to the second embodiment of the present invention may be as follows:

Step 1: Secure a first PV module **211** to a mounting surface **144** with at least one bracket **132**.

Step 2: Interlock a second PV module **211** to the first PV module **211** with at least one parallel coupling **50b** or **50j** which interlocks the sides of two adjacent frame members together in parallel.

Step 3: Attach second PV module **211** to mounting surface **144** with at least one bracket **132**.

Step 4: Repeat steps 2 and 3 for all remaining PV modules **211** in PV array **10**, successively interlocking each new PV module **211** to the side of a mounted PV module **211** and attaching at least one bracket **132** to each module.

Parallel couplings **50b** may be used at substantially all corner points **295** where four PV modules **211** meet. Substantially all brackets which are mounted in the seams between PV modules **211** may be attached via couplings **50j**. Final tightening of each coupling **50b**, **50j** and bracket **132** connection is flexible and does not necessarily coincide with

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initial placement in array **10** of that module **211**. This flexibility allows PV modules **211** to be temporarily positioned in the array while others are positioned or while wiring or other installation issues are handled. Since all couplings **50b** and **50j** are capable of being tightened from the top, PV modules **211** can be moved into locked mode at any time. One skilled in the art will recognize that the 2-axis nature of the couplings in the embodiment under discussion means that PV modules **211** can be installed in any order and in substantially any shape for PV array **10** as long as each new PV module **211** is interlocked to a mounted PV module **211**, and all new modules **211** are added to a mounted module which has a portion of a frame member **213** free (not already interlocked to another PV module). Stepped arrays as discussed above are not possible when using couplings **50b**.

In another embodiment which is similar to the first embodiment discussed above, couplings **50j** replace couplings **50a** thereby enabling the capture of brackets **132** with couplings **50j**, while also retaining the benefits of an all-parallel coupling installation as discussed.

Third Embodiment

FIGS. 32-34 depict a third embodiment of the present invention. This embodiment is similar to the first embodiment described above except that the orientation of the coupling action of coupling **50a** has been altered and a retaining element has been added. Instead of bearing against vertically oriented opposing surfaces on frame **12**, a parallel coupling **50c** is provided to bear against horizontally oriented opposing surfaces on frame **12**.

FIG. 32 shows a perspective view of parallel coupling **50c** which has been installed into slots **26A**, **26B** of two adjacent PV modules **11A**, **11B** but not fully tightened down. Frames **12A**, **12B** have been cut away so that coupling **50c** shows in this view. FIG. 33 provides an exploded view of the two sides of a retainer portion **354L**, **354R**. FIG. 34 provides a cross-section view cut through two adjacent PV modules **11A**, **11B** which are coupled together with parallel coupling **50c**. The cross section is cut partially through coupling **50c** as indicated.

Referring to FIGS. 32-34, coupling **50c** comprises retainer portion **354** which holds a locking portion **304** and a nut portion **306** via position tabs **362**. Locking portion **304** may comprise a first side **304A** for locking with frame **12A** and a second side **304B** for locking with frame **12B**. Nut portion **306** may comprise a first side **306A** for securing to frame **12A** and a second side **306B** for securing to frame **12B**. Retainer portion **354** may comprise two substantially identical halves **356L**, **356R** which mate together via male and female arm pairs **358LM**, **358RF** and **358LF**, **358RM**. Two halves **356L**, **356R** capture locking portion **304** and nut portion **306** and hold them in position as coupling **50c** is inserted into slots **26A**, **26B**. During insertion, snap-lock portions **360LA**, **360LB**, **360RA**, **360RB** flex downward then snap back up into position once inserted past flanges **108AU**, **108BU**. We contemplate making retainer portion **354** out of a plastic material, though many other semi-flexible materials are also suitable. A bolt or threaded rotating portion **300** comprises a head **352** which accepts a tool from above and is used to tighten and loosen coupling **50c** about frames **12A**, **12B**. Locking portion **304** comprises a hole for rotating portion **300** which is larger than the outside diameter of rotating portion **300** and is not threaded. Nut portion **306** is drilled and tapped for the threads on rotating portion **300** and comprises teeth **364** for biting into

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frames 12A, 12B when coupling 50c is tightened, thereby providing electrical ground continuity between modules 11A, 11B and enhancing the structural connection of coupling 50c. We contemplate making locking portion 304, and nut portion 306 out of a rigid material such as aluminum or steel, though other materials are also suitable.

Operation of the apparatus of the third embodiment is similar to the first embodiment except for the operation of coupling 50c. Coupling 50c may be pre-assembled in a factory by mating halves 356L, 356R about locking portion 304 and nut portion 306 so that coupling 50c may be deployed as a one-piece unit ready for installation in the field. To install, coupling 50c is inserted at substantially any point along slot 26A in PV module 11A. Coupling 50c is inserted with snap-lock portions 360LA, 360RA pointing towards opening 27A in slot 26A and with a direction of travel which is substantially parallel with the plane of laminate 20A and substantially perpendicular to the length of slot 26A. Coupling 50c is inserted until snap-lock portions 360LA, 360RA clear flange 108AU and snap into place. Coupling 50c is now in positioning mode and ready to be coupled to PV module 11B. With coupling 50c being held in place by retainer portion 354, PV modules 11A and 11B are free to be moved independently from each other. Thus, this embodiment provides the same independent movement capability in positioning mode as discussed above for the first embodiment, but coupling 50c is held in position during this phase by retainer portion 354 instead of locking portions 104A, 104B. To complete the coupling operation, coupling 50c is inserted into slot 26B until it snaps in place as described above. Then a driver is used to engage rotating portion head 352 and rotate rotating portion 300 which pulls nut portion 306 toward slots 26A, 26B and pushes locking portion 304 away from slots 26A, 26B.

More specifically, rotation of rotating portion 300 causes locking portion 304 and nut portion 306 to move closer together which in turn causes locking portion 304 to bear against inside surfaces 309AL, 309BL of slots 26A, 26B and nut portion 306 to bear against opposing surfaces, bottom surfaces 15A, 15B of frames 12A, 12B. Thus it is clear that coupling 50c securely interlocks PV modules 11A and 11B together by bearing against opposing surfaces on each frame 12A, 12B upon rotation of rotating portion 300. As locking portion 304 and nut portion 300 tighten about frames 12A, 12B position tabs 362 bend or break since they are overpowered by the force delivered by the driver to rotating portion 300. Once rotating portion 300 is tight, coupling 50c is now in locked mode. Sliding mode can be accessed at any time by loosening rotating portion 300, which is still accessible from the top even after array 10 has been formed. As with the first embodiment, sliding mode allows sliding of coupling 50c over to a neighboring seam 150 or 152 so that a module can be removed from the middle of a formed PV array 10.

In other embodiments a surface area of contact between locking portion 304 and frames 12A, 12B is increased by widening or removing altogether flanges 108AL, 108BL. Another embodiment extends locking portion 304 and nut portion 306 with series coupling portions so that they reach over to the next pair of modules, thereby creating a four module coupling similar the second embodiment above. In another embodiment locking portion 304 comprises a spring element for bearing against an inside surface of slot 226. In yet another embodiment retainer portion 354 is shaped differently so that it comprises spring elements for the top and bottom flanges.

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Fourth Embodiment

FIGS. 35-38 depict a fourth embodiment of the present invention. This embodiment is similar to the second embodiment as described above except that locking portions 204A, 204B and rotating portions 200 have been altered slightly.

FIG. 35 depicts a perspective view of a parallel coupling 50d installed in two adjacent PV modules 211A, 211B and FIG. 36 presents a perspective view of coupling 50d with a rotating portion 400CD which has been slid over to the right (see below for explanation). FIG. 37 provides a cross section cut through a seam between four PV modules 211A, 211B, 211C, 211D which have been interlocked together with coupling 50d, and FIG. 38 depicts a perspective view of four interlocked PV modules 211A, 211B, 211C, 211D. As is consistent with the present invention, parallel coupling 50d comprises locking portions 404AC, 404BD and rotating portions 400AB, 400CD which serve to compress frames 212 upon movement of coupling 50d into locked mode. Locking portions 404AC, 404BD differ from locking portions 104A, 104B in that they have been elongated with series coupling portions 462 to bridge between the two pairs of PV modules 211A, 211C and 211B, 211D; thus enabling coupling 50d to interlock four adjacent PV modules in a similar manner to the second embodiment except without requiring a separate series coupling portion 162. Coupling 50d is deployable in the field as a one-piece unit which is capable of interlocking four PV modules 211A, 211B, 211C, 211D together. Instead of utilizing two parallel coupling portions 50bb plus series coupling portion 162 as discussed for the second embodiment, this embodiment essentially allows two coupling members to share two locking portions 404AC, 404BD thereby creating a "double coupling" device.

Since locking portions 404AC, 404BD can no longer rotate within slots 26A, 26B, 26C, 26D to tighten coupling 50d, threaded shaft portions 402A, 402B, 402C, 402D (not all visible) replace shaft portions 232A, 232B and thread into threaded holes 490A, 490B, 490C, 490D (not all visible) in locking portions 404AC, 404BD. Opposite ends of shaft portions 402A, 402B and 402C, 402D are provided with opposite handed threads so that rotation of shaft portions 402A, 402B, 402C, 402D causes locking portions 404AC, 404BD to move horizontally in opposite directions from each other according to the arrow shown in FIG. 36. Rotating portions 400AB, 400CD replace rotating portions 100 and function the same except that rotating portions 400AB, 400CD are decoupled from shaft portions 402A, 402B, 402C, 402D allowing them to move horizontally independently from shaft portions 402A, 402B, 402C, 402D according to the arrow shown on FIG. 36. Rotating portions 400AB, 400CD, however, cannot rotate independently from their respective shaft portions 402A, 402B and 402C, 402D as they are provided with hexagonal bores 492AB, 492CD to match hexagonal portions 494AB, 494CD which may be rigidly connected or formed from shaft portions 402A, 402B and 402C, 402D respectively. In other embodiments hexagonal parts are provided with other shapes to achieve the same functionality.

Referring specifically to FIG. 37, it is evident that a rotation of rotating portion 400AB with a wrench in a first direction causes locking portions 404AC, 404BD to pull frames 212A, 212B towards each other. Since rotating portion 400AB is slidable, it slides along hexagonal shaft portion 494AB until it is contacting both outside surfaces 216A, 216B of PV modules 211A, 211B. Additional rotation in the first direction after both frames 212A, 212B have

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contacted rotating portion 400AB causes locking portion 404AC to bear against inside surfaces 209AU, 209AL of slot 226A and rotating portion 400AB to bear against an opposing frame surface, outside surface 216A. Likewise, rotation of rotating portion 400AB causes locking portion 404BD to bear against inside surfaces 209BU, 209BL of slot 226B and rotating portion 400AB to bear against an opposing frame surface, outside surface 216B. Thus, PV frames 212A and 212B are locked to coupling 50d via rotation of rotating portion 400AB. The other half of coupling 50d operates in the same way to lock frames 212C and 212D to coupling 50d. Thus it is clear that coupling 50d securely interlocks PV modules 211A, 211B, 211C, and 211D together by bearing against opposing surfaces on each frame 212A, 212B, 212C, 212D upon rotation of rotating portions 400AB, 400CD.

Once both rotating portions 400AB and 400CD have been rotated into their fully tightened positions, coupling 50d is in locked mode as discussed earlier. Rotation of rotating portion 400AB in a second direction which is opposite the first direction decouples PV modules 211A and 211B. If both rotating portions 400AB and 400CD are rotated so as to decouple PV modules 211A, 211B and 211C, 211D respectively, then coupling 50d is shifted into sliding mode and is therefore free to slide completely over into the slots of either PV modules 211A, 211B or 211C, 211D.

FIGS. 35 and 37 also reveal raised portions or teeth 496AC and 496BD on locking portions 404AC, 404BD which bite into frames 212A, 212B, 212C, 212D when coupling 50d is tightened thereby providing a reliable electrical ground connection between all four PV modules 211A, 211B, 211C, 211D and enhancing the structural properties of coupling 50d. These drawings also show optional retainer portions 454AC, 454BD on the top and bottom of locking portions 404AC, 404BD. Retainer portions 454AC, 454BD may comprise a flexible material which allows insertion of coupling 50d into a pair of slots 226A, 226B from the end but prevents coupling 50d from falling back out on its own or from sliding around prior to being shifted into locked mode. Another embodiment is the same as the fourth embodiment except only comprises one rotating portion and is approximately half as long. This embodiment functions the same but is optimized to interlock two PV modules 211 together instead of four.

The fourth embodiment provides several advantages relative to some of the other embodiments discussed herein. The sliding capability of rotating portion eliminates the need for springs 236A, 236B, 236C, 236D; incorporation of a series coupling portion 462 into locking portions 404AC, 404BD eliminates the need for series coupling portion 162; and manufacturing costs may be reduced. However, series coupling portion 462 is not as strong as series coupling portion 162 since it must be contained within slots 226A, 226B.

Additional Embodiments

FIGS. 39-40 depict a perspective view and a cross section cut between two interlocked PV modules 211A, 211B respectively for an alternate embodiment which is similar to the fourth embodiment as shown in FIGS. 35-38. This embodiment, which helps to lower manufacturing costs, provides a parallel coupling 50e in which rotating portions 400AB, 400CD have been eliminated in favor of a plurality of rotating portions 500. This arrangement enables the attachment of coupling 50e to frames 212 via a bearing action against two opposing surfaces which are both inside of slot 226 instead of one internal and one external as shown for the fourth embodiment. Locking portions 504AC,

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504BD are almost the same as before, but now retainer portions 454AC, 454BD and teeth 496AC, 496BD have been eliminated. Locking portions 504AC, 504BD are rigidly joined together by y-axis spacer block 574 with x-axis spacer screw 576. Spacer screw 576 is in place as shown during initial installation so that each module can be slid up to screw 576. But if a module needs to be removed from array 10 after complete installation, spacer screw 576 is removed and coupling 50e is slid completely over to the next horizontal seam 150. Locking portions 504AC, 504BD also comprise series coupling portions 562 as before. Rotating portions 500 comprise shaft portions 502 which may be threaded and further provided with a cupped end for biting into frames 212 to insure reliable electrical ground and to enhance the structural properties of coupling 50e. Thus, rotating portions 500 comprise a portion which resides inside of slots 226 and a portion which resides outside of frames 212. The external portion of rotating portions 500 may also comprise a hexagonal or other shaped head portion 503 which allows rotation from above similar to rotating portions 400AB, 400CD.

Referring to FIG. 40 and the coupling process between PV modules 211A, 211B, a rotation of rotating portions 500 causes them to bear against inside surfaces 507A, 507B of slots 226A, 226B thereby forcing locking portions 504AC, 504BD to bear against opposing inside surfaces 509AU, 509AL, 509BU, 509BL, thereby securely coupling the sides of adjacent PV modules 211A and 211B together. Since coupling 50e, like coupling 50d, is designed to connect four adjacent PV modules together, one skilled in the art will recognize that the coupling of modules 212C and 212D utilizes the same process as just discussed for PV modules 212A and 212B. Thus it is clear that coupling 50e securely interlocks PV modules 211A, 211B, 211C, and 211D together by bearing against opposing surfaces on each frame 212A, 212B, 212C, 212D upon rotation of rotating portions 500.

In another embodiment similar to the previous the half of locking portions 504AC, 504BD that interlock PV modules 211C, 211D together is eliminated along with series coupling portion 562. This leaves a two-module parallel coupling which is possibly suitable for use in PV array 10 along with couplings 50e (like at the ends of rows). In another embodiment a coupling is formed out of a single locking portion 504AC along with associated rotating portions 500 from coupling 50e. While this embodiment is similar to prior art series couplings, it differs significantly in that the coupling action results from a bearing on two opposing surfaces of slot 226 (for increased strength). Furthermore, there is no press-fit action and the grounding is provided by rotating portions 500. Another embodiment is similar to the embodiment of FIGS. 39-40 except that spacer block 574 is slidably held between locking portions 504AC, 504BD via pins between locking portions and is taller than slot opening 227A. This variation works similarly to the fourth embodiment except that instead of rotating portions sliding to set the spacing between modules, it is the spacer block which slides. In still another embodiment multiple spacer blocks are utilized.

FIGS. 41-42 depict a cross section cut between two interlocked PV modules 11A, 11B and a perspective view respectively for an alternate embodiment which is similar to the first embodiment as shown in FIGS. 1-24, but may lower manufacturing costs. This embodiment provides a coupling 50f with locking portions 604A, 604B which are threaded into rotating portion 600 via shaft portions 602A, 602B instead of being rigidly connected thereto. Rotating portion

600 has also been trimmed down in size so that coupling 50/ can not only be slid into the slots 26A, 26B of a neighboring pair of PV modules (in sliding mode), but so that it can also “turn the corner” and move from an x-axis direction slot into a y-axis direction slot and vice versa. This feature enables removal of a PV module even when the slots within the PV array are not aligned in one direction. This may occur in some cases by accident, or in other cases due to tolerance issues, or for architectural reasons. Springs 606U, 606L on rotating portion 600 are smaller than before but function the same. Shaft portions 602A, 602B are provided with opposite threading so that rotation of rotating portion 600 causes locking portion 604A to bear against inside surface 109AU, 109AL of slot 26A and rotating portion 600 to bear against an opposing surface, outside surface 16A of frame 12A. Likewise, locking portion 604B bears against inside surface 109BU, 109BL of slot 26B and rotating portion 600 bears against an opposing surface, outside surface 16B of frame 12B. Thus it is clear that coupling 50/ securely interlocks PV modules 11A, 11B together by bearing against opposing surfaces on each frame 12A, 12B upon rotation of rotating portion 600.

In another embodiment similar to the previous one discussed, locking portion 604A and shaft portion 602A is replaced by locking portion 104A and shaft 102A from the first embodiment.

FIGS. 43-44 depict a perspective view and a cross section cut between two interlocked PV modules 11A, 11B respectively for an alternate embodiment which is similar to the third embodiment as shown in FIGS. 32-34. This embodiment lowers the amount of installation time required by replacing rotating portion 300 with a shaft 750 and cams 780A, 780B on a parallel coupling 50g. Cams 780A, 780B are rigidly connected to rotating portion 700 which is rotatable about axle 788 with a wrench from above. Shaft 750 comprises a flat, narrow portion 774 with a hole (not visible) that shaft 788 runs through, a medium diameter portion 775, a larger diameter portion 776, and a head portion 752. A washer portion 706 with sides 706A, 706B is positioned on shaft portion 776 and comprises a bore (not viewable) larger than shaft portion 776 but smaller than a diameter of head portion 752. A locking portion 704 with sides 704A, 704B is positioned on shaft portion 775 and comprises a bore (not viewable) larger than shaft portion 775 but smaller than shaft portion 776. Locking portion 704 comprises thicker portions 785A, 785B and is pushed down onto ledge 788 by retainer springs 756A, 756B (in direction of arrow) when not installed.

To operate, cams 780A, 780B are rotated so that they are not touching locking portion 704. Then coupling 50g is snapped onto frame 12A. We contemplate making springs 756A, 756B out of a flexible material such as rubber or similar so that they allow locking portion 704 and washer portion 706 to open up when pushed onto frame 12A. Thicker portions 785A, 785B in conjunction with springs 756A, 756B prevent coupling from falling off, thus enabling positioning mode. Frame 12B and coupling 50g are wedged in the same fashion. Once coupling 50g is loosely positioned onto both frames 12A, 12B, then a wrench is used to rotate rotating portion 700 which in turn rotates cams 780A, 780B, which force locking portion 704 and washer portion 706 to move toward each other. This movement causes locking portion 704 to bear against inside surfaces 309AL, 309BL of slots 26A, 26B and washer portion 706 to bear against opposing surfaces, bottom surfaces 15A, 15B of frames 12A, 12B. Thus it is clear that coupling 50g securely interlocks PV modules 11A, 11B together by bearing against

opposing surfaces on each frame 12A, 12B upon rotation of rotating portion 700. Raised teeth 764 bite into frames 12A, 12B upon tightening, thereby ensuring ground contact and enhancing structural properties as described earlier. In another embodiment springs 756A, 756B comprise a resting position as depicted and therefore do not push locking portion down onto ledge 788 when not installed. Another embodiment provides a cam shape which sets the straight-up position as free, then rotating one direction moves to positioning mode and rotating the other way enables locked mode. And another embodiment provides a handle connected to rotating portion 700.

FIGS. 45-46 depict a perspective view and a cross section cut between two interlocked PV modules 11A, 11B respectively for an alternate embodiment which is similar to the third embodiment as shown in FIGS. 32-34. This embodiment may provide a lower manufacturing cost by replacing retainer portion 354 with retainer springs 856A, 856B between a locking portion 804 and a nut portion 806. Similar to the previous embodiment, a coupling 50h comprises retainer springs 856A, 856B which pull a locking portion 804 with sides 804A, 804B down onto a ledge 888 when not installed (in direction of arrow). Coupling 50h is snapped onto frame 12A and temporarily held in place during positioning mode by springs 856A, 856B and thicker portions 885A, 885B of locking portion 804. Thicker portions 885A, 885B may also be sized to provide a positive engagement for lateral loads. Rotation of rotating portion 300 causes the coupling to shift to locked mode as described for the third embodiment. Another variation of this embodiment provides springs 856A, 856B which are in their resting state as shown so that ledge 888 is not needed. Yet another variation replaces thicker portions 885A, 885B with teeth that interlock with frame and another provides grounding spikes on locking portion 804.

FIGS. 47-48 depict a cross section cut between two interlocked PV modules 11A, 11B and a perspective view respectively for an alternate embodiment which is similar to the first embodiment as shown in FIGS. 1-24. The primary distinction of the present embodiment, which describes a coupling 50i, is that locking portions 104A, 104B have been replaced by pairs of locking portions 904AU, 904AL and 904BU, 904BL respectively. The paired locking portions 904AU, 904AL and 904BU, 904BL are provided with ridged camming surfaces 982AU, 982AL, 982BU, 982BL which are adapted to bear against inside surfaces 909AU, 909AL, 909BU, 909BL when a rotating portion 900 is rotated. Rotating portion 900 is rigidly connected to locking portions 904AU, 904AL, 904BU, 904BL via a pair of shafts (not visible) which run through retainer portions 954A, 954B. Retainer portions 954A, 954B may be made of a flexible material so that insertion of retainer portions 954A, 954B into slots 26A, 26B deforms or bends retainer portion enabling positioning mode. Ridges on ridged camming surfaces 982AU, 982AL, 982BU, 982BL bite into frames 12A, 12B upon rotation thereby securing ground contact and increasing the strength of coupling 50i. Locking portions 904AU, 904AL, 904BU, 904BL comprise flattened portions 980A, 980B which enable insertion when properly aligned with slots 26A, 26B since they reduce the overall width to less than opening 27A, 27B. Thus, insertion of locking portions 904AU, 904AL, 904BU, 904BL into slots 26A, 26B followed by a rotation of nut portion 900 causes locking portions 904AU, 904AL, 904BU, 904BL to bear against opposing surfaces 909AU, 909AL, 909BU, 909BL, thereby securely coupling the sides of adjacent PV modules 11A and 11B together. In another embodiment locking portions

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904AU, 904AL, 904BU, 904BL are rotated 90 degrees from the orientation shown so that rotation of rotating portion 900 causes a camming action between the back of slot 26 and inside surfaces 109AL, 109AU. In another embodiment retainer portions 954A, 954B are eliminated in favor of an offset cam arrangement similar to the first embodiment where one cam is insertable in both first position 91 and second position 92.

FIGS. 49-50 depict an embodiment which is similar to the second embodiment discussed above except that a spacer block 274 has been added. FIG. 49 is the same as 26 except spacer block 274 is shown installed onto series coupling portion 162 via a slot 276 on the bottom side. FIG. 50 provides a perspective view of spacer block 274 which further reveals slot 276 and a bottom mounted wire clip 285 for securing PV module 11 output wires 22neg, 22pos. Securing wiring in this way is a substantial improvement over prior systems since wire clip 285 provides a means of preventing wires from unsightly and unsafe drooping onto roof surfaces. Furthermore, the horizontal seam 150 between PV modules 211A, 211B and 211C, 211D is set for this embodiment slightly wider than the width of wiring plugs 24neg, 24pos; therefore troubleshooting and maintenance of PV array 10 wiring systems is greatly simplified since one can easily snap spacer block 274 up and off from the top and pull wires 22neg, 22pos right up through seam 150 for inspection and repair. No decoupling of PV modules 11A, 11B is required in order to maintain the wiring system between them. In another embodiment a wire clip comprises a spring clip which snaps into slot 26A thereby allowing the strapping of wires substantially along the whole length of frame 26A. In still another embodiment a hinged wire clip 285 snaps into slot 26A and swings underneath module 11 to hide it, then back up into the gap between modules 11 to allow access.

FIGS. 51-52 depict an embodiment of the present invention which is similar to the second embodiment discussed above except that PV array 10 is installed on an open canopy structure 144C instead of roof 144R. Installation on a different mounting surface 144 for PV array 10 requires minor changes to brackets 132 and series coupling portions 162 as will be discussed below.

FIGS. 51 and 52 depict a perspective view and a side view respectively of PV array 10 installed on canopy structure 144C. Canopy 144C comprises purlins 180 which are supported by girders 182 which in turn are supported by vertical columns 184. We contemplate vertical columns 184 of approximately the same height for this embodiment in order to demonstrate that substantially any tilt angle (from flat to vertical) for PV array 10 is suitable. For example, many prior art systems require a specific slope to a PV array in order for the interlocking or mounting systems to function properly, but the coupling and framing systems described herein do not place any such limitations on PV array 10. PV array 10, as shown in FIG. 51, comprises a total of sixteen PV modules which are mechanically interlocked in groups of four with couplings 50b in the same manner described in FIGS. 25-28. Use of a different mounting surface 144 in this embodiment requires slight changes to the brackets and the layout of series coupling portions 162. The detail in FIG. 51 shows a double bracket 186 which is utilized to directly connect two frames 212 to purlins 180 in the central vertical seam 152 where the groups of four PV modules 211A, 211B, 211C, 211D come together. Double bracket 186 comprises vertical portions 187L, 187R with vertical adjustment slots 188 for connecting to frames 212 in the same way as bracket 132 only this bracket connects to two adjacent PV modules

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211. Each horizontal row along the central vertical seam 152 comprises one double bracket 186, but not all are visible here. Double bracket 186 further comprises U-bolt slots 190L, 190R (not all visible), U-bolt 192, nut and washer 193 for securing double bracket 186 to purlin 180, and a series coupling portion 962. PV modules 211 are secured to the other two purlins by means of a bracket 132U which is similar to double bracket 186 except that there is only one vertical portion 187 since this is the last row of PV modules 211.

Regarding the present embodiment under discussion, it is also important to note that there are no strut or PV frame support members required as would be the case for most prior art systems. For example, PV array 10 as shown in FIG. 51 would normally require an additional layer of PV frame support members 131PA between purlins 180 and PV frames 212 or as an alternative some prior art systems allow increasing the number of purlins shown to 8 (two per row) instead of adding another layer of structural support (thus the purlins become the PV frame support members). The inventive system of this embodiment however creates a parallel interlock support system 160 which only requires connection of PV frames 212 to the three purlins 180 as shown. In other embodiments it is desired to minimize the size of frames 212, therefore additional purlins may be used, but still not as many prior art systems require. In other embodiments brackets 132 are formed in different shapes to facilitate connection to the shape of mounting surface 144. For example, some are shaped to compress a portion of an I-shaped beam whereas others are adapted for connection to circular pipe. Still others are formed as "legs" to allow tilting up one side of an array 10. One skilled in the art will recognize that there are many different types of brackets which make up the entire scope of the inventive device. Thus, any bracket which has one portion shaped to optimize connection to a mounting surface 144 and another portion which is shaped to optimize connection to at least one PV frame 212, is a suitable bracket 132 for use with the present invention.

FIGS. 53-54 show an alternate embodiment of PV array 10 which further comprises a snap-in conduit box 195. FIG. 53 depicts a perspective view of two interlocked PV modules 12A, 12B which are at the end of a row. FIG. 54 shows a perspective view of conduit box 195. Conduit box 195 snaps into slots 26A, 26B via spring clips 197. Hole 196 in the rear of conduit box 195 allows wiring from array 10 to pass into box 195, then out through conduit 198 connected to box 195. An optional cover plate for conduit box 195, as are typical in the art, is not shown here. Use of conduit box 195 along with PV array 10 greatly simplifies wiring since all wiring can be routed through gaps between PV modules 12, then into conduit box 195 and out through conduit 198 to inverters or other system equipment. PV installers commonly fashion means for connecting junction boxes to PV array support structures via strut and other materials. However, a ready-made box saves time in cutting strut and custom rigging for each job. Conduit box 195 may also enhance the aesthetics of array 10 since it may be manufactured to match PV modules frames. In other embodiments conduit box 195 is more firmly attached to frames 12A, 12B by connecting it via bolts or couplings 50j instead of spring clips 197, in a similar way to the connection of series coupling portions as shown in the second embodiment above. In still other embodiments conduit box is replaced by a simple plate for receiving a strain relief or conduit coupling.

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FIG. 55 depicts a perspective view of an alternate embodiment of PV module 11 as shown in FIG. 1. A PV module 411 with a PV laminate 420 and a frame 412 is shown. Frame 412 comprises two frame members 413 with slots 426 on opposite sides of a laminate back plane or base 409. Devices such as base 409, as are known in the art, may serve to insulate a roof or provide structural support to PV laminate 20 or both. Base 409, however, is not rigid enough to fully support PV laminate 420, and thus frame members 413 are glued, fastened, or otherwise adhered to base 409 or laminate 420 or both in order to provide structural support to PV module 411 and to provide a means for interlocking the sides of an array of PV modules 411 together. Base 409 may be adhered to the underside of PV laminate 420. Since PV laminate 420 is supported by frame members 413 and base 409, it may overhang frame members 413 as shown. In another embodiment frame members 413 enclose base 409.

Other embodiments add different features. For example, one embodiment adds a ball and detent to locking portion 104A, 104B to prevent locking portion 104A, 104B from disengaging or working its way free and provide a position location stop. Another provides a quick-release handle attached to rotating portion 100. The handle is tucked just lower than laminate 20 height when in locked mode and can be rapidly rotated by use of a finger-hold. Such a feature may be of use to firemen in an emergency. Another embodiment provides a locking portion which comprises an expansion bolt. Other embodiments provide various devices which snap into or connect to slot 26 such as: tool holders, tools, string line holders, lights, fasteners, cosmetic flashings, architectural features, snow guards, debris screens, rodent screens, signs, cable clips, bird deterrents, and electrical connector housings.

While a number of exemplary aspects and embodiments have been discussed above, those of skill in the art will recognize certain modifications, permutations, additions and sub-combinations thereof. It is therefore intended that the following appended claims and claims hereafter introduced be interpreted to include all such modifications, permutations, additions, and sub-combinations as are within their true spirit and scope.

What is claimed as invention is:

1. A photovoltaic module and coupling assembly, comprising:

- (a) a photovoltaic module, comprising:
 - (i) a photovoltaic laminate, and
 - (ii) a frame around the photovoltaic laminate, wherein the frame has an outwardly facing groove therein,

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the outwardly facing groove having an inner slot and upper and lower flanges; and

- (b) a coupling received into the outwardly facing groove in the frame, wherein the coupling is dimensioned such that rotation of the coupling to a locked position causes the coupling to simultaneously bear against top and bottom surfaces of the inner slot, and wherein the coupling is capable of sliding along the groove while within the groove when in an unlocked position.

2. The assembly of claim 1, wherein the coupling comprises a rotating body portion with locking portions extending from opposite sides of the rotating body portion.

3. The assembly of claim 2, wherein one of the locking portions of the coupling has a length approximately equal to the height of the slot and a width slightly less than the height of an opening into the groove.

4. The assembly of claim 1, wherein outer surfaces of the upper and lower flanges are curved inwardly into an opening into the groove.

5. The assembly of claim 1, wherein the coupling rotates from the unlocked position to the locked position when rotated by 90 degrees.

6. The assembly of claim 1, wherein the coupling is locked into the groove by rotation about an axis substantially parallel to the plane of the photovoltaic laminate.

7. The assembly of claim 1, wherein the inner slot is positioned below an edge of the photovoltaic laminate.

8. The assembly of claim 1, further comprising:

(c) a second photovoltaic module, comprising:

- (i) a photovoltaic laminate, and
- (ii) a frame around the photovoltaic laminate, wherein the frame has an outwardly facing groove therein, the outwardly facing groove having an inner slot and upper and lower flanges,

and wherein rotation of the coupling to the locked position causes the coupling to simultaneously bear against the top and bottom surfaces of the inner slots in the frames around both the first and second photovoltaic modules.

9. The assembly of claim 8, wherein the coupling comprises a rotating body portion with locking portions extending from opposite sides of the rotating body portion, and wherein one locking portion is disposed within the outwardly facing grooves of each of the first and second photovoltaic module frames.

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